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Research Article

The Effect of Wall Covering Form Used in Offices on Users' Perceptual Evaluations

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Abstract

Wall surfaces are the vertical planes that dominate the user's field of vision in interior spaces, and the form and colour tone of the materials applied to them are decisive in shaping spatial perception. Although the effects of colour on interior perception are well documented, the joint effect of covering geometry and wood colour tone in office environments, and the way this joint effect interacts with user demographics, remain insufficiently examined. This study investigates the effects of the geometric form (square/circular) and colour tone (light/dark) of wooden wall coverings used in offices on users' perceptual evaluations, together with the effects of gender, age, profession and work experience. Four photorealistic open-plan office scenarios (square-light, square-dark, circular-light, circular-dark) identical in every respect except covering form and colour were modelled in 3ds Max and presented to participants as 360-degree virtual space tours. A total of 219 volunteers evaluated the four environments on a seven-point semantic differential scale composed of 15 bipolar adjective pairs (Cronbach's alpha = 0.951). Data were analysed through one-way analysis of variance and Tukey HSD post-hoc tests. Colour tone produced significant differences in all 15 adjective pairs ($p < 0.001$): light-toned environments were perceived more positively than dark-toned ones throughout. The effect of form emerged independently in the affective dimensions, with the circular-light environment evaluated as the warmest and most intimate condition. Gender, age, profession and work experience all produced significant differences. The findings provide designers with an evidence-based guide for wall surface decisions in offices.

Keywords: Colour Tone, Form, Office, Spatial Perception, Wooden Wall Covering

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INTRODUCTION

As Churchill (1943, p. 317) expressed it, "we shape our buildings; thereafter they shape us" a remark that strikingly summarises the reciprocal interaction between people and space. The built environment does not merely leave a visual impression on the user; it also produces effects at mental, emotional and physical levels, and individuals develop strong responses to the spaces they inhabit (Roberson & Crumpton, 2022). Space stands at the centre of architectural research not only in its physical dimensions but also in its sociological, psychological and behavioural aspects. Lefebvre (1991) argues that space intersects with the production process of social relations and that architectural design and the built environment are directly connected to social, political, economic and ideological dynamics: while the individual transforms space, space simultaneously shapes the individual's perceptions and experiences. Kuban (2002) similarly maintains that architectural space should be defined not only through its formal properties but also through its qualities relating to human life, and that what renders space meaningful is the relationship its boundaries establish with the human being.

Individuals spend the greater part of their lives in architectural spaces such as dwellings, educational buildings, workplaces and healthcare facilities, and well-designed environments increase both the joy of living and productivity (Hasol, 2023). People spend approximately 87% of their daily time indoors (Klepeis et al., 2001), and in modern society this proportion reaches more than 70% of the lifespan (Kim & Rigdon, 1998). Among these indoor environments, offices occupy a particular position. Kroemer and Kroemer (2001) note that office employees spend roughly half of their waking hours in the office environment, which brings to the fore the necessity of designing these spaces in accordance with user comfort and highlights the effect of office arrangements on quality of life, employee productivity and institutional performance. Adults spend approximately one third of their lives, around 90,000 hours, at work (Harvard Division of Continuing Education, 2023). Although interest in remote working models has increased in recent years, open-plan office applications are still widely preferred in many institutions because of their flexibility and cost advantages. Research has demonstrated that the physical conditions of the workplace significantly affect employees' perceptions, attitudes and performance (Elsbach & Bechky, 2007). Erkan and Ozanözgü (2022) emphasise that office buildings are important spaces that should be evaluated in the context of their relationship with the user, and that spatial factors must be taken into account during the design process. Gerçek (2020) notes that workplace layout is frequently reported in the literature as being influential on variables such as status, belonging, organisational culture, productivity, job satisfaction and psychological well-being.

Vision is the dominant mode of perception in human beings and constitutes the basis of environmental perception (Rapoport, 1977). Understanding the relationship established with space requires examining how the individuals perceive that relationship. Visual perception plays a fundamental role in the individual's interpretation of environmental information; the fact that a large proportion of the signals transmitted to the central nervous system originate from the eye reveals the dominant effect of visual sensation on environmental perception (Lawson, 2001).

Wall surfaces used in interiors are among the most powerful carriers of these visual elements. Aydıntan (2016) argues that the majority of the visual messages intended to be conveyed in interiors are loaded onto vertical surfaces, and that these surfaces are regarded as "focal surfaces" because they attract user

attention most strongly. Ching (2022) states that wall planes occupy a dominant place in the user's field of vision owing to their vertical orientation and play a determining role in the enclosure and formal perception of space. Çomak (2020) notes that because walls are located at eye level, design decisions concerning them directly affect the user experience, and that a sense of meaning and identity regarding the space is conveyed to the user through the materials applied to their surfaces.

The covering materials preferred on wall surfaces are among the principal elements determining the perceptual quality of the surface. Aydıntan (2001) argues that in the selection of surface covering materials not only visual aesthetics but also the function of the space and the message to be conveyed should be taken into account. Soygeniş (2023) states that the texture of the wall element creates differences in spatial perception by reflecting the properties of the material used, and that stone, concrete, brick or wood coverings become important design components that strengthen perception by offering the user both visual and tactile experiences.

Form is defined by Onat (1995) as the formal order that emerges through the continuity of the boundaries determining the general shape of an object. Aytem (2005) states that form is one of the design components to which designers show the greatest sensitivity, owing to its three-dimensional character compared with the two-dimensional effects of colour and texture. The square possesses a hidden structural skeleton composed of central vertical, horizontal and diagonal axes, and within this skeleton it produces a sense of order, balance and discipline (Arnheim, 1974). The circle, having central symmetry from every direction, is the simplest form, described as the "primordial form"; having neither direction nor corner, it appears both as the child's first organised drawing and as a universal figure representing the universe and wholeness (Arnheim, 1974). Aydınlı (1986) states that rectangular forms create a balanced and dynamic effect, narrow-angled forms an unbalanced and disturbing effect, and circular forms a relaxing and restful effect. Arnheim (1974) likewise notes that when rotated about its centre the square is perceived as mobile and the circle as serene, summarising this phenomenon as "rotation for the square, rest for the circle".

Ateş and Özel (2023) state that colour changes made on the same form can transform perception. Alici and Paktaş (2020) note that warm and cool colours preferred particularly on walls affect the dimensional qualities of space such as width, height and airiness; warm colours make the space feel narrower, lower and closer, while cool colours produce a wider, higher and airier perception. Aytem (2005) emphasises that the designer must take into account how spatial effects will influence the individual in order to design spaces in which people can feel comfortable and at ease and which increase work productivity.

Various studies have demonstrated that wood used in office environments produces positive effects on users' psychological and physiological responses, reduces anxiety and stress levels, stabilises blood pressure and renders perceptions of the space more positive (Jiménez et al., 2016; Ojala et al., 2023; Sakuragawa et al., 2005). Zhu et al. (2023) determined that offices with light- and medium-toned wood were evaluated by users as aesthetically more positive than those with dark tones, and that spaces with lower wood coverage were preferred to those with higher coverage. Poirier et al. (2019) found that light-coloured and warm wood coverings, particularly oak, contributed to brighter, more relaxing and more productive environments in daylit interiors, the model covered with dark walnut was found to be darker and duller, with female participants in particular evaluating dark environments more negatively.

Another determining factor in spatial perception is the individual's demographic characteristics. Ertürk (1984) notes that even when individuals experience the same environmental conditions they may perceive that environment differently, and that these differences arise from characteristics such as age, gender, physical condition and level of expertise. Studies have shown that individuals with design education focus more on aesthetics and arrangements in the architectural environment and develop a more critical view towards environmental stimuli, whereas individuals without design education prioritise the functional and utilitarian dimensions of space (Coşgun et al., 2022; Ergün et al., 2023). Müezzinoğlu et al. (2020) determined that individuals without design education evaluated spaces dominated by chromatic colours more positively, while individuals with design education evaluated spaces designed with cool colours more positively. Gifford et al. (2002) and Yazdanfar et al. (2015) likewise report systematic differences between the environmental judgements of architects and laypersons. Gender differences in spatial perception have also been documented: some studies report that male participants evaluate environmental factors more positively, while others report that female participants perceive certain space types more positively (Coşgun et al., 2022; Author et al., 2007b). A concrete example of the effect of age difference on perception is seen in Hertzberger's design for an elderly care home in Amsterdam, reported by Rapoport (1990): the "perceptual unity" the architect sought to establish through a balance of white skeleton and black infill produced negative associations of "crosses and coffins" among the elderly residents, clearly demonstrating how differences in age and experience can transform design decisions. Stamps (1999), in a meta-analysis of demographic effects in environmental aesthetics, similarly concludes that demographic variables must be systematically taken into account in perception research.

The effect of form, colour, material and demographic characteristics on spatial perception has been documented in recent comprehensive studies. Author et al. (2021) revealed that in spaces using wall panels of different geometric forms, circular panels in particular were perceived by users as warmer, airier and more intimate. Coşgun et al. (2022) determined that light-coloured wooden wall coverings were perceived more positively than dark-coloured materials and that light-coloured wooden surfaces in particular added warmth to the space. Tutar and Author (2023) demonstrated that wall covering arrangements were influential on spatial perception in open-plan offices with three different covering layouts, while Güneş et al. (2019) determined that the colours used in offices were a decisive element in employees' perceptual quality and performance.

The international literature has likewise documented that variables such as colour, form and material proportion on interior wall surfaces play a determining role in user perception. Kwallek (1996), Kwallek et al. (1997) and Kwallek et al. (2005) revealed that office wall colour significantly affects the perception of spaciousness, employees' mood and work performance, and that light tones in particular make the space appear airier. Savavibool and Moorapun (2017) determined that neutral and cool colours in office spaces make the environment feel airier and more orderly, whereas warm and multicoloured environments are perceived as narrower and more complex. Ahmed et al. (2024) examined the effects of different wall colours (red and blue) on users' thermal comfort perception in a virtual reality environment and demonstrated that colour choice can directly affect spatial perception and comfort.

Another important development in spatial perception research in recent years is the use of virtual reality (VR) technology as an experimental tool. Mineev (2017) defines virtual reality as a real or simulated environment enabling the perceiver to

feel present through a medium of communication, and notes that this property makes it an effective tool particularly in research on spatial perception and user experience. Sherman and Craig (2003) state that virtual reality is an effective instrument in the architectural field, especially in architectural walkthroughs, design spaces and virtual prototyping applications, making the experience of architectural spaces possible at lower cost. Hidayetoğlu et al. (2012) state that virtual environments enable accurate results to be obtained at far lower cost than real environment scenarios, and emphasise that the literature clearly demonstrates the usability of virtual environments in scientific studies. Cha et al. (2020) examined the effects of four different colour schemes (red, green, blue and white) on users' emotional states, task performance and heart rates in an office-like virtual interior, and demonstrated that VR technology is an effective method for evaluating user responses and spatial perception. Banaei et al. (2017) and Banaei et al. (2020) reported that digital environments constitute an important alternative for users' experience and perception of space, while Ma et al. (2025) demonstrated the effectiveness of immersive virtual reality in end-user design review. Accordingly, VR technology offers a convenient, controlled and repeatable research environment for examining the perceptual effects of wall covering form and colour in offices.

These divergent findings in the literature indicate that spatial perception cannot be reduced to a single rule or formula. Ertürk (1984) emphasises with the statement that "there is no suitable cookbook for good architectural design" that the design process cannot be reduced to standard rules, and that each space must be approached in a manner that takes into account its own context and user characteristics.

Within this framework, although the effects of colour on interior perception have been examined extensively, studies that address the geometric form and colour tone of wooden wall coverings together in office environments, that measure this joint effect through 360-degree virtual space tours rather than static visual presentations, and that simultaneously analyse the moderating role of user demographics, remain limited. The present study is designed to address this gap.

Aim of the Research

The aim of this study is to reveal the effects of the geometric form (square/ circular) and colour tone (light/dark) variables of wooden wall coverings used in office spaces on users' spatial perception. Accordingly, four different virtual office environments were designed on the basis of two form and two colour variables; the spaces, modelled in a photorealistic environment, were presented to participants as 360-degree virtual space tours. Gibson (2015) notes that a picture or drawing offers limited visual information and cannot convey movement and depth in the way real visual perception does; for this reason, 360-degree virtual space tour technology was preferred as an effective instrument capable of conveying spatial experience realistically. Participants' perceptual evaluations were measured through a semantic differential scale containing 15 adjective pairs, and the effects of demographic variables such as age, gender, profession and work experience on spatial perception were also analysed.

Significance of the Research

Theoretically, the study contributes to the environmental perception and architectural psychology literature by supporting the spatial outcomes of form and colour variables with quantitative data. Methodologically, it offers an innovative experimental setup that goes beyond static visual presentations through 360-degree virtual space tours. Practically, it serves as a user-oriented

guide for interior architects, architects and office designers in wall surface design decisions.

Limitations

This study has certain limitations. The scope of the research is confined to the office environment; in the design of the wall coverings only the form and colour variables were addressed, and other variables such as texture and proportion were excluded. Although virtual environments provide a high degree of realism, they cannot fully simulate the multisensory experience (thermal, acoustic, olfactory and so on) of physical space.

Hypotheses of the Research

On the basis of the publications on spatial perception reviewed above, the research hypotheses formed in relation to the wall covering form and colour tone variables are as follows:

H1: Office spaces in which circular-form wooden wall coverings are used will be perceived and evaluated more positively by participants than spaces in which square-form coverings are used.
H2: Office spaces in which light-toned wooden wall coverings are used will be perceived and evaluated more positively by participants than spaces in which dark-toned coverings are used.
H3: Female participants will perceive and evaluate the physical environmental factors of offices using wooden wall coverings more negatively than male participants.
H4: There will be significant differences between participants' age groups in terms of the perceptual evaluation of office spaces using wooden wall coverings.
H5: Architect and engineer participants will perceive and evaluate the physical environmental factors of offices using wooden wall coverings more negatively than participants in other occupational groups.
H6: There will be significant differences between participants' lengths of work experience in terms of the perceptual evaluation of office spaces using wooden wall coverings.

MATERIAL AND METHOD

Research Model

In order to test the research hypotheses formulated in the introduction, a questionnaire was developed and administered to volunteer participants in an online environment; the general survey model was used as the research method. The study analysed participants' perceptual evaluations of wooden wall coverings with different geometric forms (square/circular) and colour tones (light/dark) used in office spaces.

Population and Sample

A total of 219 participants voluntarily took part in the research in an online environment. The sample size of participants selected to represent the research population was considered sufficient. Information regarding the gender, age, profession and work experience of the participants constituting the sample is presented in Table 1.

As seen in Table 1, 58.4% of the participants are female and 41.6% are male. In terms of age distribution, the largest group (46.6%) consists of participants aged 26–35, followed by the 18–25 age group with 27.9%, the 36–45 age group with 14.6% and the group aged 46 and over with 11.0%. According to the occupational distribution, 22.4% of the participants are architects, 22.8% are engineers and 54.8% belong to other occupational groups. According to the

distribution of work experience, 47.0% of the participants have 1–3 years of work experience, 14.2% have 4–6 years, 13.2% have 7–10 years, and 25.6% have 11 years or more of experience.

Data Collection Tools

In line with the aim of the study, a questionnaire was developed to determine the effect of the geometric form (square/circular) and colour tone (light/dark) variables of wooden wall coverings used in office spaces on users' perceptual evaluations. During the preparation of the questionnaire the literature in the fields of environmental perception and architectural psychology was reviewed in detail, and scales whose validity and reliability had been demonstrated in previous studies were taken as the basis.

Table 1. General information on the participants (produced by the authors).

Participant information		n	%
Gender	Female	128	58.4
	Male	91	41.6
Age	18–25	61	27.9
	26–35	102	46.6
	36–45	32	14.6
	46 and over	24	11.0
Profession	Architect	49	22.4
	Engineer	50	22.8
	Other	120	54.8
Work experience	1–3 years	103	47.0
	4–6 years	31	14.2
	7–10 years	29	13.2
	11 years and over	56	25.6

Note: n: Number of participants, %: Percentage value.

The questionnaire forms designed to test the research hypotheses consist of two main sections. The first section covers participants' general demographic information, and the second section contains questions evaluating the spatial quality of offices with different wall forms and colours. The design of the research questionnaire was based on a seven-step semantic differential scale composed of 15 bipolar adjective pairs ordered from 1 to 7 (1: positive, 7: negative), which was found valid and reliable in studies previously conducted by İmamoğlu (1975), Author (1999), Author et al. (2005), Author et al. (2007a), Author et al. (2007b), Author et al. (2007c), Akalın et al. (2009), Author et al. (2011), Author, Çağatay and Ayalp (2015), Author, Çağatay and Hidayetoğlu (2015) and Özkan and Author (2016). This scale comprises the adjective pairs beautiful/ugly, warm/cold, brightness/darkness, roomy/cramped, attractive/repulsive, airy/gloomy, high/low, intimate/formal, orderly/disorderly, well-planned/poorly planned, large/small, free/restricted, simple/complex, peaceful/disturbing and uncrowded/crowded.

In order to facilitate participants' understanding of the research questionnaire and to ensure the authenticity of the responses given, an explanatory and consent text was added at the beginning of the questionnaire, thereby securing responses only from volunteer participants interested in the subject. The questionnaire administration was supported by 360-degree virtual space tours so that participants could experience the environments more realistically. Participants navigated each virtual office scenario interactively and subsequently answered the questionnaire items. This method went beyond static visuals and offered a high level of realism and contextual evaluation. The questionnaires were completed in approximately 15 minutes using an online form created

through Google Forms during June 2025. The research data obtained from these questionnaires were subsequently analysed using the IBM SPSS Statistics software (version 22.0).

Research Environment

Virtual prototypes are increasingly preferred over their high-cost physical counterparts (Bayraktar & Kaleli, 2007). In this study, 360-degree virtual space tour technology was used in modelling offices with two different wall covering forms and two different colours as the experimental environment. Banaei et al. (2017, 2020) reported in their studies that digital environments can constitute an important alternative for users' experience and perception of space. The virtual environments of the offices in which the experiments were conducted were modelled by taking 360-degree renders with the 3ds Max programme. The four environments are also made openly accessible as interactive 360-degree tours so that the stimuli used in the study can be inspected and reused by other researchers (see the note under Figure 1). The offices modelled for this experimental study are square in plan with an area of 500 m². All physical properties of these spaces other than the wall covering form (square/circular) and colour (light/dark) were held constant. In order to measure the perceptual effect of the wall coverings arranged in two different forms in the office spaces, the light wood and dark wood colours whose Natural Colour System (NCS) and Red, Green, Blue (RGB) codes are given in Table 2 were used.

Table 2. Wood colours used in the virtual office spaces (produced by the authors).

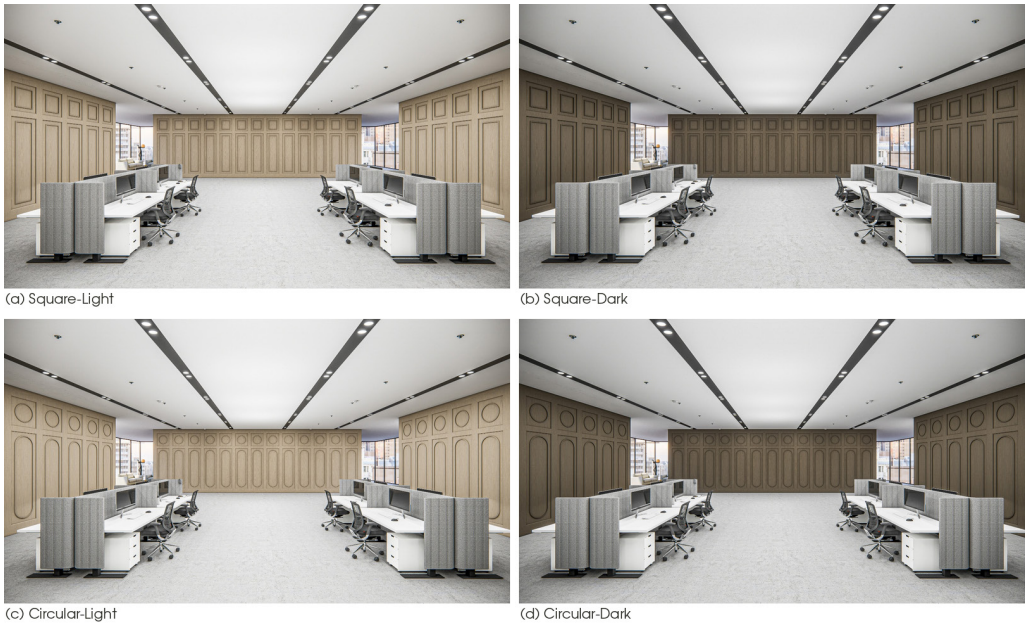
Material colours	NCS and RGB colour codes	Image
Light wood	NCS: S 2020-Y40R — R: 205, G: 180, B: 145	
Dark wood	NCS: S 5015-Y50R — R: 115, G: 95, B: 75	

Note: NCS: Natural Colour System, RGB: Red, Green, Blue Colour System.

The four different virtual office spaces created using the colours given in Table 2 (square-light, square-dark, circular-light, circular-dark) are presented in Figure 1.

Analysis of the Data

In the research, participants' perceptual evaluations of office spaces with different wall covering conditions were defined as dependent variables, while the form (square/circular) and colour tone (light/dark) of the wall covering together with participants' differences in gender, age, profession and years of experience were defined as independent variables. First, Cronbach's alpha internal consistency analysis was conducted to assess the reliability of the questionnaire data. Subsequently, frequency, percentage, mean and standard deviation values were calculated within the scope of descriptive statistics. One-way analysis of variance (ANOVA) was applied to determine the differences between groups according to the dependent variables, and for variables showing significant differences the necessary post-hoc analyses (Tukey's honestly significant difference, HSD) were performed to determine at which levels the groups diverged. Mean values of the variables were reported through tables and figures.



(a) Square-Light (b) Square-Dark

(c) Circular-Light (d) Circular-Dark

Figure 1. Virtual office spaces with four different wall coverings (produced by the authors).

Note: The four scenarios are available as interactive 360-degree tours at the following addresses: https://cloud.chaos.com/collaboration/n/JgAq1pKNpoU1HB9tvoeTDG/present / Square-Light
https://cloud.chaos.com/collaboration/n/91AuLgqBaHwn6q1gS9sWfD/present / Square-Dark
https://cloud.chaos.com/collaboration/n/FiALj5toJaVpQLM11m5xxm/present / Circular-Light
https://cloud.chaos.com/collaboration/n/FaGPn9bWBU6c31SQGDeUGF/present / Circular-Dark

FINDINGS

This study investigated the differences between participants' perceptual evaluations of the physical environmental factors of different office scenarios created according to the geometric form (square/circular) and colour tone (light/dark) variables of the wooden wall coverings used in office spaces. In addition, it examined whether participants' gender, age, profession and work experience variables had an effect on the perceptual evaluations of office spaces in which wooden wall coverings were used. The findings that emerged as a result of the analyses are presented systematically below.

Reliability Analysis

First, Cronbach's alpha reliability analysis were conducted on the data concerning the dependent variables of the research, and the reliability values of the items and of the scale are given in Table 3.

Table 3. Results of the reliability analysis (produced by the authors).

Dependent variables	Item reliability	Scale reliability
Beautiful/Ugly	0.947	0.951
Warm/Cold	0.951	0.951
Brightness/Darkness	0.946	0.951
Roomy/Cramped	0.948	0.951
Attractive/Repulsive	0.949	0.951
Airy/Gloomy	0.950	0.951
High/Low	0.944	0.951
Intimate/Formal	0.947	0.951
Orderly/Disorderly	0.946	0.951
Well-planned/Poorly planned	0.947	0.951
Large/Small	0.945	0.951
Free/Restricted	0.948	0.951
Simple/Complex	0.949	0.951
Peaceful/Disturbing	0.950	0.951
Uncrowded/Crowded	0.947	0.951

As shown in Table 3, the reliability coefficient of the scale composed of 15 adjective pairs was determined as 0.951. Cronbach (1951) explained that alpha reliability coefficients may be accepted as reliable when they exceed the value of 0.70 for all items. The Cronbach's alpha coefficients of this study range between 0.944 and 0.951 for all items constituting the dependent variables, and these values are above 0.70. According to this result, the research data may be accepted as highly reliable.

Findings Related to Wooden Wall Covering Form and Colour Tone

The differences between participants' perceptual evaluations of the physical environmental factors of office spaces using wooden wall coverings arranged in four different configurations (square-light, square-dark, circular-light, circular-dark) were tested; the mean and standard deviation values of the results obtained, together with Tukey HSD homogeneity groups and ANOVA test results, are given in Table 4.

Table 4. Results relating to participants' evaluations according to wooden wall covering form and colour tone (produced by the authors).

Dependent variables	Square-Light	Square-Dark	Circular-Light	Circular-Dark	F	df	Sig.
Beautiful/Ugly	3.01 (1.57) A	3.61 (1.75) B	2.74 (1.58) A	3.70 (1.80) B	16.876	3	0.000*
Warm/Cold	3.51 (1.69) B	4.04 (1.69) C	3.05 (1.66) A	3.96 (1.65) C	16.214	3	0.000*
Brightness/Darkness	2.84 (1.55) A	3.95 (1.70) B	2.57 (1.45) A	4.02 (1.66) B	48.227	3	0.000*
Roomy/Cramped	2.80 (1.54) A	3.56 (1.64) B	2.67 (1.51) A	3.69 (1.56) B	24.179	3	0.000*
Attractive/Repulsive	3.26 (1.60) A	3.78 (1.65) B	3.00 (1.68) A	3.88 (1.68) B	14.011	3	0.000*
Airy/Gloomy	3.25 (1.70) A	3.98 (1.63) B	2.93 (1.65) A	3.98 (1.66) B	22.258	3	0.000*
High/Low	2.85 (1.44) A	3.49 (1.63) B	2.74 (1.50) A	3.50 (1.61) B	15.019	3	0.000*
Intimate/Formal	3.83 (1.80) B	4.58 (1.84) C	3.02 (1.77) A	4.20 (1.62) BC	31.706	3	0.000*
Orderly/Disorderly	2.42 (1.48) A	3.07 (1.57) B	2.59 (1.38) A	3.14 (1.55) B	12.082	3	0.000*
Well-planned/Poorly planned	2.92 (1.69) A	3.33 (1.52) B	2.80 (1.49) A	3.57 (1.47) B	11.664	3	0.000*
Large/Small	2.84 (1.48) A	3.30 (1.52) B	2.77 (1.42) A	3.40 (1.54) B	9.998	3	0.000*
Free/Restricted	3.39 (1.72) AB	3.78 (1.60) B	3.05 (1.66) A	3.79 (1.65) B	9.949	3	0.000*
Simple/Complex	2.64 (1.45) A	3.32 (1.58) B	2.87 (1.60) A	3.44 (1.65) B	12.592	3	0.000*
Peaceful/Disturbing	3.26 (1.61) A	3.91 (1.70) B	3.06 (1.57) A	4.00 (1.66) B	17.916	3	0.000*
Uncrowded/ Crowded	2.98 (1.60) A	3.62 (1.64) B	2.93 (1.55) A	3.74 (1.69) B	14.581	3	0.000*

*Note: Cells show M (SD) followed by the Tukey HSD homogeneity group. * significant at p < 0.001. M: Mean value, SD: Standard deviation, F: F value, df: Degrees of freedom. Mean values of variables ranked from 1 to 7; higher values indicate more negative responses.*

The mean values given in Table 4 show that there are significant differences between participants' perceptual evaluations of the physical environmental factors of office spaces using wooden wall coverings arranged in four different ways. According to the results of the one-way analysis of variance conducted to determine whether these differences are statistically significant, significant differences were found for all adjective pairs constituting the semantic differential scale (at the p < 0.001 level). These results are expressed graphically in Figure 2.

As seen in Figure 2, there are significant differences between participants' perceptual evaluations of the physical environmental factors of office spaces using wooden wall coverings arranged in four different ways. According to the results of the Tukey HSD post-hoc analysis, significant differences were found in thirteen of the fifteen adjective pairs examined (beautiful/ugly, bright/dark, roomy/cramped, attractive/repulsive, airy/gloomy, high/low, orderly/disorderly, well-planned/poorly planned, large/small, free/restricted, simple/complex, peaceful/disturbing and uncrowded/crowded) between light-toned spaces

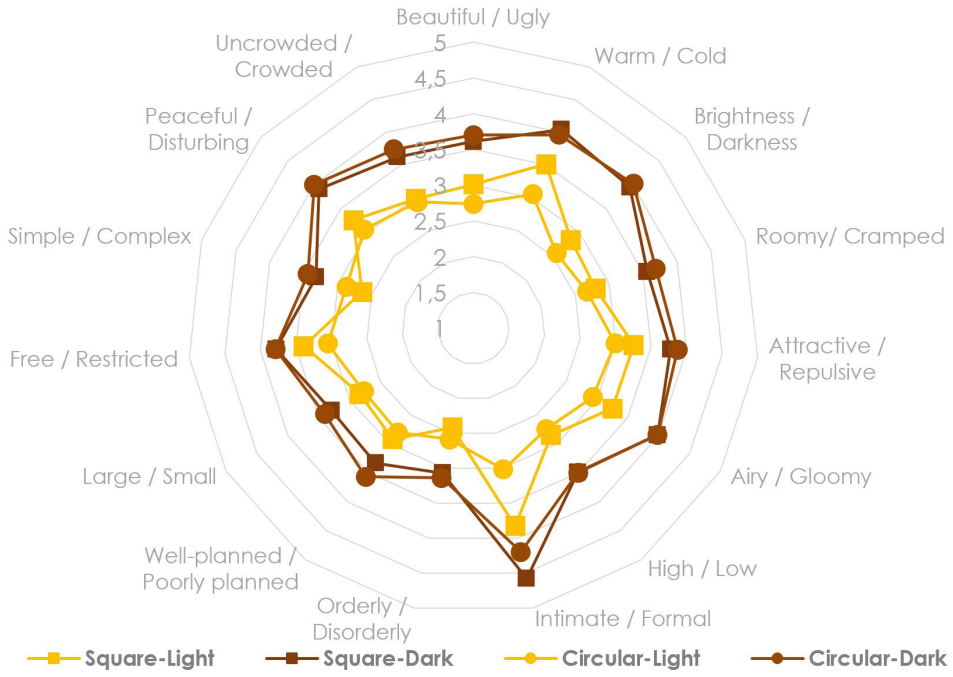


Figure 2. Mean evaluations relating to the wooden wall coverings used in office spaces (produced by the authors).

(square-light and circular-light) and dark-toned spaces (square-dark and circular-dark); in general, light-toned spaces were assigned to homogeneity group A, whereas dark-toned spaces were assigned to homogeneity group B ($p < 0.05$). In general, light-toned spaces did not differ significantly among themselves, nor did dark-toned spaces among themselves.

On the other hand, the effect of form came to the fore in the warm/cold and intimate/formal adjective pairs. In the warm/cold dimension the circular-light space alone was determined as homogeneity group A (the warmest), while the square-light space fell into homogeneity group B and the dark-toned spaces into homogeneity group C (the coldest). Similarly, in the intimate/formal dimension the circular-light space alone was determined as homogeneity group A (the most intimate); this indicates that the circular form, when used together with a light colour tone, has a marked positive effect on the perception of intimacy and warmth.

These results show that the form (square/circular) and colour tone (light/dark) variables of the wooden wall coverings used in office spaces have important effects on participants' perceptual evaluations. They reveal that the effect of colour tone is generally more dominant than that of form, whereas the effect of form emerges distinctly in the affective and relational dimensions in particular (warmth and intimacy).

Findings Related to Gender

The mean and standard deviation values and ANOVA test results covering the differences between participants' spatial perceptions of the physical environmental factors of office spaces using wooden wall coverings according to gender are given in Table 5.

As shown in Table 5, significant differences (at the $p < 0.05$ level) were found between participants' spatial perceptions of the physical environmental factors of office spaces using wooden wall coverings according to gender for the adjective pairs warm/cold ($p = 0.011$), attractive/repulsive ($p = 0.007$), simple/complex ($p = 0.034$) and peaceful/disturbing ($p = 0.009$).

Table 5. Results relating to participants' evaluations according to gender (produced by the authors).

Dependent variables	Female	Male	F	df	Sig.
Beautiful/Ugly	3.34 (1.75)	3.16 (1.69)	2.357	1	0.125 ns
Warm/Cold	3.77 (1.75)	3.47 (1.65)	6.490	1	0.011*
Brightness/Darkness	3.42 (1.80)	3.25 (1.59)	1.994	1	0.158 ns
Roomy/Cramped	3.14 (1.68)	3.24 (1.54)	0.738	1	0.391 ns
Attractive/Repulsive	3.61 (1.72)	3.30 (1.63)	7.256	1	0.007*
Airy/Gloomy	3.62 (1.82)	3.41 (1.55)	3.070	1	0.080**
High/Low	3.12 (1.62)	3.18 (1.53)	0.281	1	0.596 ns
Intimate/Formal	3.99 (1.85)	3.79 (1.85)	2.472	1	0.116 ns
Orderly/Disorderly	2.75 (1.54)	2.88 (1.50)	1.372	1	0.242 ns
Well-planned/Poorly planned	3.22 (1.59)	3.06 (1.56)	2.123	1	0.146 ns
Large/Small	3.01 (1.54)	3.18 (1.47)	2.559	1	0.110 ns
Free/Restricted	3.54 (1.77)	3.45 (1.58)	0.544	1	0.461 ns
Simple/Complex	2.97 (1.66)	3.20 (1.51)	4.492	1	0.034*
Peaceful/Disturbing	3.68 (1.73)	3.38 (1.61)	6.915	1	0.009*
Uncrowded/Crowded	3.28 (1.70)	3.37 (1.60)	0.547	1	0.460 ns

*Note: Cells show M (SD). * significant at p < 0.05 and ** significant at p < 0.10. ns: not significant at p > 0.10. M: Mean value, SD: Standard deviation, F: F value, df: Degrees of freedom. Mean values of variables ranked from 1 to 7; higher values indicate more negative responses.*

No significant gender-related difference was found for the remaining eleven adjective pairs. The graphical representation of these results is given in Figure 3. As seen in Figure 3, male participants perceived office spaces using wooden wall coverings as more beautiful, warm, bright, attractive, airy, intimate, well-planned and peaceful than female participants, whereas female participants perceived them as more roomy, orderly, large and simple than male participants. In general, it may be stated that female participants displayed a more negative attitude in spatial perception than male participants.

Findings Related to Age

The mean and standard deviation values and ANOVA test results covering the differences between participants' spatial perceptions according to age group are given in Table 6.

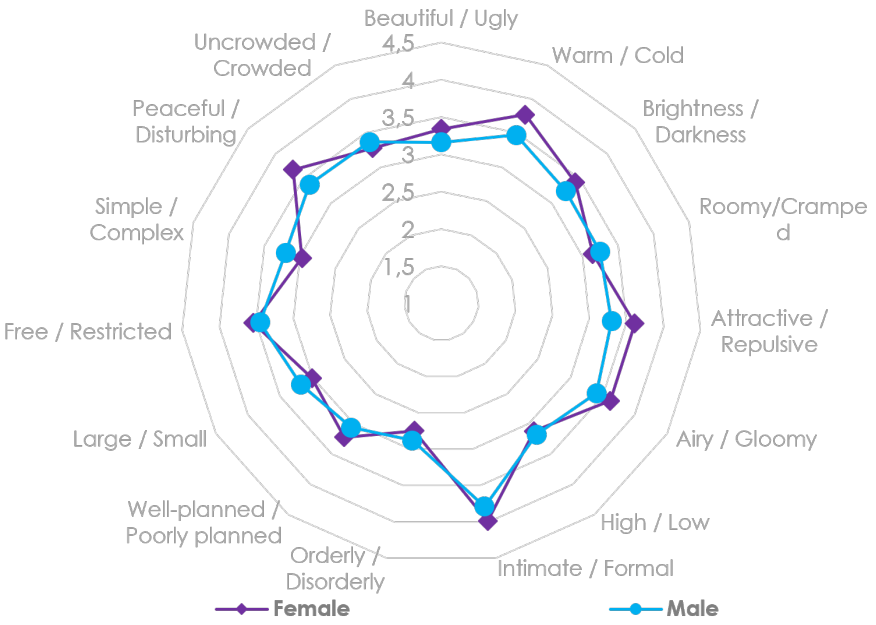


Figure 3. Effect of participants' gender on the dependent variables (produced by the authors).

Dependent variables	18–25	26–35	36–45	46 and over	F	df	Sig.
Brightness/Darkness	3.50 (1.80)	3.39 (1.77)	3.04 (1.41)	3.19 (1.60)	2.393	3	0.067**
Roomy/Cramped	3.27 (1.76)	3.21 (1.66)	3.13 (1.35)	2.90 (1.38)	1.348	3	0.258 ns
Attractive/Repulsive	3.68 (1.58)	3.49 (1.75)	3.25 (1.65)	3.24 (1.68)	2.601	3	0.051**
Airy/Gloomy	3.75 (1.70)	3.47 (1.81)	3.45 (1.54)	3.38 (1.60)	1.847	3	0.137 ns
High/Low	3.23 (1.69)	3.04 (1.55)	3.24 (1.46)	3.24 (1.58)	1.088	3	0.353 ns
Intimate/Formal	4.20 (1.78)	3.91 (1.90)	3.53 (1.70)	3.68 (1.88)	4.308	3	0.005*
Orderly/Disorderly	2.95 (1.61)	2.77 (1.56)	2.80 (1.35)	2.57 (1.35)	1.603	3	0.187 ns
Well-planned/Poorly planned	3.34 (1.57)	3.16 (1.67)	3.09 (1.44)	2.76 (1.28)	3.278	3	0.020*
Large/Small	3.18 (1.53)	3.04 (1.56)	3.19 (1.40)	2.85 (1.42)	1.394	3	0.243 ns
Free/Restricted	3.62 (1.66)	3.57 (1.77)	3.43 (1.57)	3.04 (1.53)	3.037	3	0.028*
Simple/Complex	3.26 (1.68)	2.97 (1.61)	3.19 (1.57)	2.82 (1.35)	2.619	3	0.050**
Peaceful/Disturbing	3.68 (1.60)	3.62 (1.76)	3.49 (1.53)	3.07 (1.69)	3.334	3	0.019*
Uncrowded/Crowded	3.44 (1.66)	3.30 (1.71)	3.41 (1.57)	2.93 (1.52)	2.376	3	0.069**

Table 6. Results relating to participants' evaluations according to age group (produced by the authors).

*Note: Cells show M (SD). * significant at p < 0.05 and ** significant at p < 0.10. ns: not significant at p > 0.10. M: Mean value, SD: Standard deviation, F: F value, df: Degrees of freedom. Mean values of variables ranked from 1 to 7; higher values indicate more negative responses.*

As shown in Table 6, significant differences (at the p < 0.05 level) were found according to participants' age groups for the adjective pairs beautiful/ugly (p = 0.044), warm/cold (p = 0.001), intimate/formal (p = 0.005), well-planned/poorly planned (p = 0.020), free/restricted (p = 0.028) and peaceful/disturbing (p = 0.019). The graphical representation of these results is given in Figure 4.

As seen in Figure 4, young participants in the 18–25 age range evaluated office spaces using wooden wall coverings more negatively than the other age groups; spatial perception developed positively as age increased, and participants aged 46 and over made the most positive evaluations. According to these results it may be stated that perception of offices with wooden materials is positively affected as age groups advance.

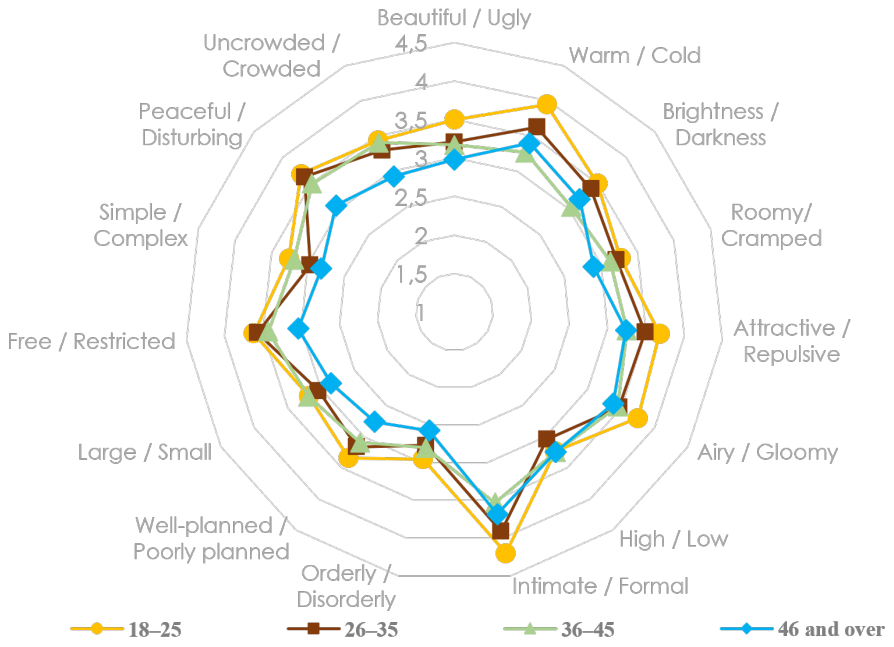


Figure 4. Effect of participants' age groups on the dependent variables (produced by the authors).

Findings Related to Profession

The mean and standard deviation values and ANOVA test results covering the differences between participants' spatial perceptions according to occupational group (architect, engineer, other occupations) are given in Table 7.

As shown in Table 7, significant differences (at the $p < 0.05$ level) were found according to participants' occupational groups for the adjective pairs beautiful/ ugly ($p = 0.022$), warm/cold ($p < 0.001$), attractive/repulsive ($p = 0.001$), airy/ gloomy ($p = 0.003$), intimate/formal ($p = 0.002$), free/restricted ($p = 0.015$) and peaceful/disturbing ($p = 0.007$). The graphical representation of these results is given in Figure 5.

As seen in Figure 5, architect and engineer participants evaluated office spaces using wooden wall coverings with mean values close to one another, whereas participants in the "other" occupational group evaluated the offices generally more negatively than architects and engineers. These results show that occupational groups with design or technical education, such as architects and engineers, adopt a more positive approach in their perceptions of office spaces than participants in the "other" occupational group.

Table 7. Results relating to participants' evaluations according to occupational group (produced by the authors).

Dependent variables	Architect	Engineer	Other	F	df	Sig.
Beautiful/Ugly	3.11 (1.59)	3.07 (1.60)	3.41 (1.81)	3.852	2	0.022*
Warm/Cold	3.40 (1.60)	3.24 (1.46)	3.91 (1.81)	13.651	2	0.000*
Brightness/Darkness	3.31 (1.64)	3.17 (1.51)	3.44 (1.82)	1.883	2	0.153 ns
Roomy/Cramped	3.24 (1.56)	3.19 (1.51)	3.15 (1.69)	0.207	2	0.813 ns
Attractive/Repulsive	3.22 (1.61)	3.25 (1.61)	3.68 (1.73)	7.634	2	0.001*
Airy/Gloomy	3.31 (1.55)	3.33 (1.50)	3.72 (1.85)	5.977	2	0.003*
High/Low	3.20 (1.51)	3.05 (1.46)	3.16 (1.66)	0.519	2	0.595 ns
Intimate/Formal	3.65 (1.79)	3.69 (1.78)	4.11 (1.88)	6.234	2	0.002*
Orderly/Disorderly	2.83 (1.38)	2.72 (1.35)	2.83 (1.65)	0.401	2	0.670 ns
Well-planned/Poorly planned	3.04 (1.39)	3.00 (1.49)	3.27 (1.68)	2.783	2	0.062**
Large/Small	3.24 (1.53)	3.14 (1.39)	2.99 (1.55)	2.258	2	0.105 ns
Free/Restricted	3.27 (1.52)	3.39 (1.56)	3.65 (1.80)	4.243	2	0.015*
Simple/Complex	3.10 (1.43)	3.26 (1.55)	2.98 (1.68)	2.278	2	0.103 ns
Peaceful/Disturbing	3.36 (1.58)	3.36 (1.58)	3.72 (1.75)	5.011	2	0.007*
Uncrowded/ Crowded	3.28 (1.56)	3.40 (1.63)	3.30 (1.71)	0.343	2	0.710 ns

*Note: Cells show M (SD). * significant at $p < 0.05$ and ** significant at $p < 0.10$. ns: not significant at $p > 0.10$. M: Mean value, SD: Standard deviation, F: F value, df: Degrees of freedom. Mean values of variables ranked from 1 to 7; higher values indicate more negative responses.*

Findings Related to Work Experience

The mean and standard deviation values and ANOVA test results covering the differences between participants' spatial perceptions according to length of work experience are given in Table 8.

As shown in Table 8, significant differences (at the $p < 0.05$ level) were found according to participants' lengths of work experience for the adjective pairs warm/cold ($p = 0.001$), attractive/repulsive ($p = 0.002$), airy/gloomy ($p = 0.036$), well-planned/poorly planned ($p = 0.013$), free/restricted ($p = 0.041$) and peaceful/disturbing ($p = 0.009$). The graphical representation of these results is given in Figure 6.

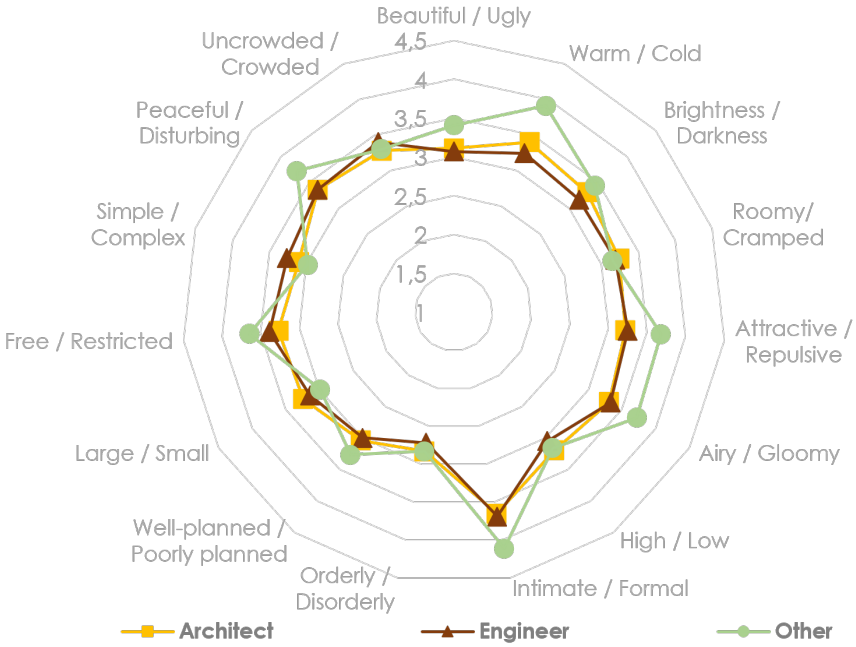


Figure 5. Effect of participants' occupational groups on the dependent variables (produced by the authors).

Table 8. Results relating to participants' evaluations according to years of experience (produced by the authors).

Dependent variables	1–3 years	4–6 years	7–10 years	11 years and over	F	df	Sig.
Beautiful/Ugly	3.35 (1.71)	3.42 (1.78)	2.97 (1.60)	3.17 (1.76)	2.064	3	0.103 ns
Warm/Cold	3.85 (1.77)	3.70 (1.65)	3.26 (1.58)	3.42 (1.66)	5.477	3	0.001*
Brightness/Darkness	3.50 (1.79)	3.25 (1.61)	3.11 (1.59)	3.24 (1.67)	2.303	3	0.076**
Roomy/Cramped	3.19 (1.64)	3.29 (1.82)	3.08 (1.50)	3.16 (1.55)	0.357	3	0.784 ns
Attractive/Repulsive	3.64 (1.60)	3.52 (1.78)	2.98 (1.63)	3.41 (1.78)	4.871	3	0.002*
Airy/Gloomy	3.66 (1.73)	3.55 (1.76)	3.13 (1.42)	3.52 (1.80)	2.854	3	0.036*
High/Low	3.17 (1.59)	3.00 (1.65)	3.09 (1.49)	3.21 (1.59)	0.538	3	0.656 ns
Intimate/Formal	4.02 (1.78)	4.10 (1.86)	3.67 (1.77)	3.72 (1.97)	2.370	3	0.069**
Orderly/Disorderly	2.81 (1.54)	2.94 (1.61)	2.78 (1.40)	2.73 (1.52)	0.550	3	0.648 ns
Well-planned/Poorly planned	3.31 (1.54)	3.17 (1.73)	2.81 (1.43)	3.04 (1.60)	3.612	3	0.013*
Large/Small	3.01 (1.46)	3.23 (1.64)	3.03 (1.48)	3.14 (1.56)	0.821	3	0.483 ns
Free/Restricted	3.59 (1.67)	3.63 (1.85)	3.10 (1.46)	3.00 (1.53)	2.762	3	0.041*
Simple/Complex	3.02 (1.62)	3.42 (1.78)	2.97 (1.46)	3.00 (1.53)	2.372	3	0.069**
Peaceful/Disturbing	3.71 (1.65)	3.66 (1.71)	3.16 (1.49)	3.43 (1.79)	3.914	3	0.009*
Uncrowded/Crowded	3.30 (1.59)	3.52 (1.87)	3.12 (1.43)	3.33 (1.76)	1.212	3	0.304 ns

*Note: Cells show M (SD). * significant at p < 0.05 and ** significant at p < 0.10. ns: not significant at p > 0.10. M: Mean value, SD: Standard deviation, F: F value, df: Degrees of freedom. Mean values of variables ranked from 1 to 7; higher values indicate more negative responses.*

As seen in Figure 6, participants with 7–10 years of work experience evaluated office spaces using wooden wall coverings more positively than the other experience groups, whereas participants with 1–3 and 4–6 years of work experience perceived the spaces more negatively. Among participants with 11 years or more of experience the scores declined slightly again, which suggests that in the mid-career period (7–10 years) individuals accumulate sufficient professional familiarity and mature their frames of reference regarding office environments.

DISCUSSION

In this section, the findings obtained in the present study are discussed in comparison with previous studies in this field. The research examined the effects

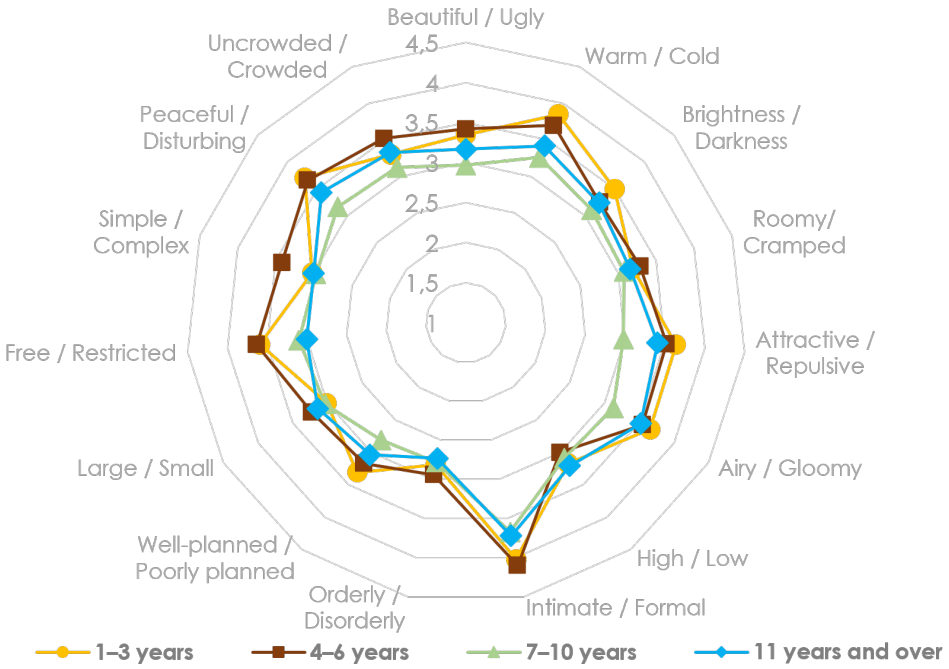


Figure 6. Effect of participants' work experience groups on the dependent variables (produced by the authors).

of the geometric form (square/circular) and colour tone (light/dark) variables of wooden wall coverings used in office spaces, together with participants' demographic characteristics (gender, age, profession and work experience), on spatial perception. The findings obtained revealed significant differences for all six hypotheses. While some of the findings show direct parallels with studies in the literature, findings relating to certain demographic variables diverge from the tendencies reported there.

According to the research findings, the form of the wall covering (square/circular) used in office spaces has a significant effect on participants' perceptual evaluations. The dimension in which the effect of form manifested itself most distinctly on its own was intimacy and warmth; spaces using circular-form and light-toned coverings were perceived as more intimate and warmer than the other space types. This result supports the findings obtained in the studies of Banaei et al. (2017), Dazkir and Read (2012), Vartanian et al. (2013) and Author and Müezzinoğlu (2024), which reveal the positive effect of circular forms on affective and relational dimensions. Vartanian et al. (2019) further demonstrated that the preference for curvilinear contour in interior architectural spaces holds among both experts and non-experts, which is consistent with the fact that in the present study the advantage of the circular-light condition emerged across the sample as a whole. In addition, in an earlier study by the authors (Author et al., 2021), which examined three different geometric forms in bedrooms, the circular-form wall panel was found to be perceived as warmer, more intimate, more attractive and more peaceful than square and triangular forms, and this finding directly supports the form finding of the present study. On the other hand, in the remaining perceptual dimensions the effect of form did not emerge as distinctly as the effect of colour tone. This suggests that form operates primarily on the affective register of spatial experience, while the perceptual dimensions concerning luminance, spaciousness and order are governed predominantly by colour tone.

The strongest finding obtained in the research is the determining effect of the colour tone (light/dark) of the wooden wall covering on perceptual evaluations. In almost all of the fifteen perceptual dimensions examined, spaces using light-toned wooden coverings were evaluated statistically significantly more

positively than spaces using dark-toned coverings ($p < 0.001$). This result shows a direct parallel with the study of Coşgun et al. (2022), which is the work most directly related to the research subject and methodologically closest to the present study; that study tested wooden, concrete and metal wall coverings in café environments and determined that light-coloured wooden coverings were the warmest and generally the most positively evaluated covering. Furthermore, the studies conducted by the same research group on colour strongly support this finding: Author et al. (2007a) in a real café-restaurant environment, Author et al. (2011) in two different living rooms, Author, Çağatay and Ayalp (2015) in classroom environments, Hidayetoğlu et al. (2012) in the context of indoor wayfinding, and Aksoy Özler et al. (2023) in interior spaces, all determined that light and warm colour tones produced significantly more positive perceptual evaluations than dark tones. The finding is also consistent with the international literature. Zhu et al. (2023) determined that offices with light- and medium-toned wood were aesthetically evaluated more positively than those with dark tones, and that lower wood coverage was preferred to higher coverage; Poirier et al. (2019) found that light-coloured wood coverings in daylit interiors contributed to brighter and more relaxing environments while dark walnut was found darker and duller. Kwallek (1996) and Kwallek et al. (1997, 2005) likewise demonstrated that light wall tones increase the perception of spaciousness in offices and positively affect mood and performance. The convergence of these findings indicates that the luminance level of the wall surface functions as a primary determinant of interior perception across space types and cultures.

The research findings revealed that participants' gender has a significant effect on spatial perception. Female participants evaluated the spaces more critically than male participants in the dimensions of warmth, attractiveness and peacefulness, whereas in the dimension of simplicity male participants perceived the spaces as more complex. This result shows a direct parallel with the gender difference results consistently obtained by the same research group in different space types: Author et al. (2007a) in a café-restaurant environment, Author et al. (2007b) in open-plan offices, Coşgun et al. (2022) in a wall covering material study and Ergün et al. (2023) in an open-plan office study all determined that male participants evaluated spaces more positively than female participants. In an earlier study by the authors (Author et al., 2024), female participants likewise evaluated bedroom environments more negatively in fourteen of the fifteen adjective pairs. Poirier et al. (2019) similarly reported that female participants evaluated dark-coloured environments more negatively. The consistency of this pattern across space types suggests that gender-related differences in environmental evaluation are systematic rather than incidental, and that they should be taken into account particularly in the design of shared work environments.

The research determined that participants' age groups have a significant effect on spatial perception; young participants in the 18–25 age range evaluated the spaces more negatively than the other age groups, spatial perception developed positively as age increased, and participants aged 46 and over made the most positive evaluations. This result shows a direct parallel with two recent studies. Yan and Guo (2023) found an inverted-U relationship between the proportion of wood covering and psychological acceptance in the activity rooms of elderly care buildings in China, and revealed that elderly participants evaluated wooden spaces positively. Mao et al. (2024) demonstrated that age has significant effects on design evaluation in office environments; while determining that the combination of wooden flooring and brown furniture was the most positively evaluated condition on average, they found that when age groups were examined separately, older participants distinctly preferred wooden

textures. Stamps (1999) likewise reports in his meta-analysis that age is among the demographic variables producing systematic effects in environmental aesthetics. The finding may be interpreted through the mere exposure effect described by Zajonc (1968): older participants, having accumulated longer exposure to wood-clad work environments, may have developed more positive attitudes towards them.

The research findings revealed that participants' occupational groups have a significant effect on spatial perception. While architect and engineer participants evaluated the office spaces with mean values close to one another, participants in the "other" occupational group evaluated the spaces distinctly more negatively. This result was not found to be consistent with the findings of an earlier study by the authors (Author et al., 2024), in which architects and interior architects made more negative evaluations than engineers and other occupational groups in thirteen of fifteen adjective pairs in bedrooms. Nor is it consistent with the studies of Coşgun et al. (2022) and Ergün et al. (2023), which determined that participants with design education made more critical evaluations, or with the finding of Gifford et al. (2002) and Yazdanfar et al. (2015) that architects and laypersons judge buildings differently. This divergence may be explained in part by the fact that the space evaluated in the present study is an office environment: architects and engineers, being themselves habitual users of office environments, may have evaluated the presented scenarios against a professional frame of reference in which the modelled offices appeared of above-average quality, whereas participants in the "other" group, whose occupational experience of office environments is more heterogeneous, may have applied a different and more demanding standard. The finding indicates that the effect of professional education on perception is not uniform across space types but is contingent on the degree to which the space type coincides with the evaluator's own professional experience. This constitutes the point at which the present study most clearly diverges from the literature, and it merits further investigation.

The research findings revealed that participants' lengths of work experience have a significant effect on spatial perception; participants with 7–10 years of work experience evaluated the spaces most positively among the groups, while participants with 1–3 and 4–6 years of experience made more negative evaluations. This result supports the findings obtained in the studies of Hidayetoğlu et al. (2010), which revealed that spatial experience systematically affects perception, and of Erdoğan et al. (2013), which stated that familiarity is an important antecedent of positive perception. Zajonc's (1968) mere exposure effect and Purcell's (1986) schema discrepancy model explain the effect of work experience from two complementary perspectives. According to Zajonc's model, the fact that the 7–10 year experience group, corresponding to the mid-career period, made the most positive evaluations may be explained by these individuals having accumulated sufficient professional familiarity and developed positive attitudes towards office environments. Purcell's schema discrepancy model, on the other hand, explains the negative evaluations in the early career period (1–3 and 4–6 years): these individuals, who still have limited office experience, may have perceived a greater discrepancy between the idealised office image they hold and the space presented, and therefore made more critical evaluations. This situation also largely coincides with the findings for the young (18–25) age group in the present study, which suggests that age and work experience operate through a shared mechanism of familiarity and schema formation.

CONCLUSION

This research aimed to determine the effects of the geometric form (square/circular) and colour tone (light/dark) variables of wooden wall coverings used in office spaces, together with participants' demographic characteristics (gender, age, profession and work experience), on users' perceptual evaluations. In the research, 219 participants experienced four different office scenarios (square-light, square-dark, circular-light, circular-dark) supported by 360-degree virtual space tours and were asked to make evaluations on a seven-point semantic differential scale composed of fifteen adjective pairs.

According to the results obtained in relation to the geometric form of the wooden wall covering, the dimension in which the effect of form manifested itself most distinctly on its own was intimacy and warmth. Spaces using circular-form coverings were perceived as more intimate and warm than spaces using square-form coverings, whereas in the other perceptual dimensions the effect of form did not emerge as distinctly as the effect of colour. According to these findings, hypothesis H1, which predicted that circular-form coverings would be perceived more positively than square-form coverings, was partially supported. According to the results obtained in relation to the colour tone of the wooden wall covering, statistically significant results were obtained for all fifteen adjective pairs ($p < 0.001$). Spaces using light-toned wooden coverings were perceived as more beautiful, warm, bright, roomy, attractive, airy, intimate, well-planned, simple and peaceful. According to these findings, hypothesis H2, which predicted that light-toned coverings would be perceived more positively than dark-toned coverings, was supported.

In the evaluation made according to participants' gender, significant differences were determined for the adjective pairs warm/cold, attractive/repulsive, simple/complex and peaceful/disturbing. Female participants perceived the office spaces as colder, more repulsive and more disturbing than male participants, while male participants perceived the spaces as more complex than female participants. According to these findings, hypothesis H3, which predicted that female participants would evaluate the spaces more negatively than male participants, was partially supported.

In the evaluation made according to participants' age groups, significant differences were determined for the adjective pairs beautiful/ugly, warm/cold, intimate/formal, well-planned/poorly planned, free/restricted and peaceful/disturbing. Participants in the 18–25 age group evaluated the spaces most negatively, and participants aged 46 and over evaluated the spaces most positively. According to these findings, hypothesis H4, which predicted that there would be significant differences between age groups in terms of perceptual evaluation, was supported.

In the evaluation made according to participants' professions, significant differences were determined for the adjective pairs beautiful/ugly, warm/cold, attractive/repulsive, airy/gloomy, intimate/formal, free/restricted and peaceful/disturbing. While architect and engineer participants evaluated the office spaces with mean values close to one another, participants in the "other" occupational group evaluated the spaces distinctly more negatively. According to these findings, hypothesis H5, which predicted that architect and engineer participants would evaluate the spaces more negatively than other occupational groups, was not supported; contrary to the prediction, the difference arose from the more negative evaluations of participants in the other occupational group.

In the evaluation made according to participants' lengths of work experience, significant differences were determined for the adjective pairs warm/cold, attractive/repulsive, airy/gloomy, well-planned/poorly planned, free/restricted and peaceful/disturbing. Participants with 7–10 years of work experience evaluated the spaces most positively, while participants with 1–3 and 4–6 years of experience made more negative evaluations. According to these findings, hypothesis H6, which predicted that there would be significant differences between lengths of work experience in terms of perceptual evaluation, was supported.

Taken together, these results indicate that in office interiors the luminance of the wood tone is the primary determinant of perceptual quality, while covering geometry operates as a secondary but distinct instrument acting specifically on the affective register of the environment. For designers, this suggests a two-stage decision logic: light wood tones should be preferred as the default where a positive general perception is sought, and circular or curvilinear covering geometries should be introduced where warmth and intimacy are the intended atmospheric qualities, as in reception areas, meeting rooms or collaborative zones within open-plan offices. The demographic findings further indicate that a single design solution will not be perceived uniformly by all user groups, and that the demographic composition of the intended user population should be considered as a design input rather than an afterthought.

The following recommendations are offered for the development of this study. Addressing the findings obtained from virtual office spaces in real office environments in future research will increase the generalisability of the results and broaden the contribution to the literature. The study focused predominantly on visual perception; more comprehensive research taking into account multisensory variables such as tactile perception, acoustic comfort and lighting may be conducted. Only two geometric forms, square and circular, were addressed in the present study; in future studies the inclusion of different formal arrangements such as triangular, hexagonal, organic or free forms may reveal the effect of form on spatial perception more comprehensively. The colour variable was examined through two tones, light and dark; studies addressing different colour families (warm–cool), saturation levels and colour combinations together may investigate the effect of colour on spatial perception in greater depth. Finally, the present research was limited to the office environment; examining similar variables in spaces of different functions such as housing, educational buildings, healthcare facilities and accommodation buildings may increase the generalisability of the findings.

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Conflict of Interest

No conflict of interest was declared by the authors.

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Ethics Committee Approval

Ethics committee approval was obtained from the [institution blinded for review] Ethics Committee, dated 11.07.2025 and numbered 2025 - 1225.

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In this research, the necessary permissions were obtained from relevant individuals, institutions, and organizations during the survey, in-depth interview, focus group interview, observation or experiment.

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Research Article

A Post-Humanist Spatial Analysis of the Novel: The End of the World As We Know It

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Abstract

Post-humanism is a critical approach that questions the anthropocentric structure of humanism, rethinking the relationships between humans, nature, technology, and non-human entities. This study aims to analyse the spatial structure in Erlend Loe's novel, The End of the World As We Know It, within the framework of post-humanist theory. The study examines how the spatial structure in the novel reflects the fundamental characteristics of post-humanist thought by redefining the human-nature-technology relationship. The research employs qualitative content analysis, and the novel is examined using a close reading technique. Spatial sections in the text are evaluated according to the categories of radical, mediated, methodological, critical, and pessimistic post-humanism.

The findings show that space in the novel transforms around four main axes: escape from the city to nature, hybrid living spaces formed by the interaction of nature and technology, interspecies symbiosis between humans and animals, and a critique of modern technology. It was found that the category of mediated post-humanism is particularly prominent in the novel, making visible new forms of life supported by technology within nature. The analyses also reveal that the protagonist's spatial experiences question modern life, anthropocentric thought, and the boundaries between human and non-human beings. The manifestations of this spatial transformation within the residential interior become visible through furniture, technological equipment, energy infrastructure, and arrangements for interspecies use. Consequently, the study reveals how post-humanist thought is represented in literature through spatial constructs. The research makes an original contribution by operationalising existing post-humanist categories via spatial indicators, thereby systematically analysing the relationships among humans, nature, technology, and non-human actors within the spaces of the novel. Thus, an interdisciplinary link is established between post-humanist theory and architectural spatial analysis through the medium of literary texts.

Keywords: Literature, Novel, Post-humanism, Space, The End of the World As We Know It.

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INTRODUCTION

Humanism developed as an intellectual approach that attributes qualities such as reason, autonomy, and free will to the human being, thereby positioning the human as the fundamental value, the subject of knowledge, and an entity holding a privileged status distinct from other beings (Kale, 1992). Post-humanism, on the other hand, questions this central position of the human. It views the human not as a subject independent of nature, technology, and non-human entities, but as a being shaped through reciprocal relationships with these elements. Consequently, while the humanist approach positions the human as the primary subject that makes sense of and transforms the world, the post-humanist approach proposes a relational structure in which agency is distributed among humans, non-human living beings, technological systems, and environmental elements. Similarly, Braidotti's zoe-centric approach highlights the interdependence of human and non-human entities by refusing to limit the concept of life solely to the human (Braidotti, 2014, 2019).

Scientific and technological advancements have significantly transformed the relationships humans establish with their environment and with entities other than themselves. Mechanisation, which accelerated particularly after the Industrial Revolution along with biotechnology, robotic systems, and artificial intelligence applications that have evolved since the twentieth century, has rendered the boundaries between humans, machines, and nature increasingly permeable. This transformation has led to humans being viewed not merely as producers and users of technology, but also as subjects shaped by technological systems. This interplay among humans, nature, and technology has paved the way for discussions on post-humanist thought across various disciplines, such as literature, architecture, and spatial studies (Çelik, 2019; Gündoğan, 2019; Sağlam, 2021; Şen et al., 2019).

Literary texts open for discussion the relationships humans establish with nature, technology, and non-human entities not merely at an intellectual level, but also through diverse ways of life and spatial configurations. Post-humanist literary studies highlight themes such as post-human identity, the technological body, human-animal relations, the return to nature, and critiques of modern life (Buran, 2020; Dağ, 2018; Yılmaz, 2020). However, there is a need for further research that systematically examines through various theoretical categories of post-humanism how these relationships are reflected in the formation and transformation of space. Approaching literary space from this perspective allows one to move beyond viewing space merely as the physical backdrop of a narrative. Instead, it enables an understanding of space as a relational structure where encounters between humans, nature, technology, and non-human actors unfold.

The End of the World As We Know It, the final installment in Erlend Loe's three-book Doppler series, centres on the protagonist's return to the city after withdrawing from modern life, his efforts to reintegrate into the social order, and the contradictory relationship he establishes between nature and technology. The novel intertwines spatial transitions from city to nature, technology-enabled living spaces, human-animal coexistence, and a critique of modern consumer culture. The fact that the protagonist, despite rejecting modern life, utilises technological tools and establishes a shared existence with a non-human creature demonstrates that the novel highlights the interdependencies and contradictions between nature and technology, rather than positing a strict opposition between them. Due to these characteristics, the work is considered a fitting example for examining the spatial dimensions of post-humanist thought.

In this study, space is considered not only as a physical place where events take place, but also as a narrative plane where relationships between people, nature, technology, and non-human beings are established, transformed and deciphered. The analysis focuses on the relationships established by the interior components such as housing, room, kitchen, furniture, technological equipment, and energy infrastructure with human and non-human users in addition to the general spatial transitions in the novel. The aim of the research is to analyse the spatial fiction in the novel, The End of the World As We Know It, through the categories of radical, mediated, methodological, critical, and pessimistic post-humanism. In line with this purpose, the following research questions were sought to be answered:

1. How is the spatial fiction in the novel, The End of the World As We Know It, shaped within the framework of radical, mediated, methodological, critical, and pessimistic post-humanism categories?
2. How are the relationships between humans, nature, technology, and non-human beings represented through general spatial patterns and the functional, furnishing, and technical infrastructure components of the residential interior fittings?

The original contribution of the study is that, rather than proposing a new method, it establishes a systematic analytical relationship between descriptions of space, spatial actions, technological components, and interspecies usage practices in literary text by deconstructing existing post-humanist categories through spatial indicators. The research also provides an interdisciplinary contribution by linking literary deconstruction with the relational space, user diversity, reinforcement, and technical infrastructure discussions of architecture and interior architecture.

Method

This study is descriptive qualitative research that examines the spatial fiction in Erlend Loe's novel, *The End of the World As We Know It,* within the framework of post-humanism theory. In the research, close reading and qualitative content analysis were used as two complementary analytical stages. Close reading is a text analysis technique based on the careful and continuous examination of the word, sentence, content, and form characteristics of a text to reveal the details and different layers of meaning (Akbaş, 2025). Close reading in this study was applied in order to determine the context of the narrative sections, the relationships established by the characters with the space, and the meaning of spatial transformations in the whole narrative.

Qualitative content analysis has been used as a systematic analysis method based on coding meaningful units in the text, classification under theoretical categories, comparison, and interpretation of the relationships between them (Bilgin, 2014; Miles & Huberman, 1994; Baltacı, 2019). Thus, narrative sections whose contextual meanings were determined through close reading were systematically classified and compared in accordance with the post-humanist categories previously defined through content analysis.

The primary data source for the research is the Turkish edition published with the translation by Dilek Başak (Loe, 2021). The analysis was carried out on the descriptions of space, spatial actions, character–space relations, and human–nature–technology patterns contained in this edition. The study is not a translation research that examines lexical or stylistic features or differences between the original text and the translation. The novel excerpts presented in the English version of the article were translated into English by the researcher from the Turkish edition that served as the basis for the analysis. The page numbers given

in the citations belong to the Turkish edition. However, it was accepted that the lexical and semantic preferences of the translator could affect the interpretation of the spatial narrative. The lack of direct examination of the original Norwegian text was considered one of the methodological limitations of the research.

Determination of Analysis Units

The unit of analysis of the study was formed by narrative sections in which the place in the novel is not only named but also participates in the establishment or transformation of the characters' relationships with people, nature, technology, and non-human beings. The selection criteria of the text sections have been determined in advance on the basis of research questions and human–nature, human-technology, and human–non-human relations defined in a theoretical framework. In this regard, four selection criteria were used: (i) space descriptions related to nature, cities, residential areas, or temporary living spaces; (ii) spatial actions such as settling, leaving, adapting, and transforming space; (iii) the relationship of technological objects or infrastructures such as tents, pellet systems, and domestic devices with space; (iv) arrangements for human and non-human beings to share the same space. Expressions that only state the place, name the environment in which the events took place, or do not carry an analytical response in terms of post-humanist relations were not included in the scope of the evaluation.

The identification and coding of the sections were performed manually by the researcher. The analytical process was carried out in three stages. In the first stage, the novel was read from beginning to end in order to grasp the narrative as a whole and its spatial context. In the second stage, the text was re-read in accordance with the previously determined inclusion and exclusion criteria. Narrative sections containing spatial transformation or relational dynamics were recorded together with their page numbers and narrative contexts. In the third stage, each selected section was examined in terms of the type of space, spatial actions, human and non-human actors, technological or environmental components, and the nature of the relationships among these actors. Thus, the text fragments were not determined in a free or random manner, but through a systematic close reading process based on predefined criteria.

Coding and Category Assignment Process

A theory-oriented, deductive approach was adopted in the coding process. The post-humanism approaches of Tamar Sharon, Rosi Braidotti, and David Roden have been synthesised. Five analytical categories have been created: radical, mediated, methodological, critical/zoe-centric and pessimistic post-humanism, which have been studied within a theoretical framework. In order for these categories to be applied to the spatial structure of the novel, each category has been associated with distinctive spatial indicators.

Instances where the distinction between humans and nature blurs and the shift from the city to nature comes to the fore are coded as "radical"; Instances where the relationship among humans, nature, and technology is re-established via a technological tool were coded as 'mediated'; instances where relational networks between humans and non-human entities are organised through everyday spatial practices were coded as 'methodological" ; instances highlighting interspecies coexistence ecological responsibility, and sustainable systems as "critical/zoe-centric"; and instances demonstrating the oppressive or negative effects of technology on humans and space as "pessimistic" post-humanism.
The categories were not treated as mutually exclusive classes. Multiple coding was applied when a single narrative segment encompassed more than one

post-humanist relationship; however, the analytical distinction between categories was based on the nature of the dominant relationship within the segment. The "mediated" category was employed when technology functioned as a tool enabling life within nature; the "methodological" category was used when the focus was on the mode of organising the everyday relationship between human and non-human actors; and the "critical/zoe-centric" category was applied when the ethical and ecological dimensions of coexistence were the determining factors. Thus, while making multiple theoretical dimensions of the same space visible, the conceptual distinction between the categories was preserved.

Formulation and Interpretation of Findings

The coded narrative excerpts were compared in terms of category definitions and spatial indicators; excerpts exhibiting similar relationships were grouped under high-level spatial patterns. As a result of this comparison, four fundamental patterns were identified: (i) withdrawal from the city to nature, (ii) hybrid living spaces formed by the coexistence of nature and technology, (iii) interspecies coexistence between humans and animals, and (iv) a critique of the spatial effects of modern technology. While five theoretical categories served as tools for coding and interpretation, the four spatial patterns were derived by analytically synthesising the commonalities among excerpts coded under different categories.

In interpreting the findings, the excerpts were not treated merely as examples of the relevant categories; rather, the characters' spatial experiences, the functions of the excerpts within the narrative, and the post-humanist contradictions emerging within the same space were considered collectively. To enhance the traceability of the analytical process, category definitions, spatial indicators, and their corresponding novel excerpts are presented together in Table 3. The interpretations in the findings section were also linked to the novel excerpts and relevant theoretical approaches. However, the fact that the coding and interpretation process was conducted by a single researcher was acknowledged as a limitation inherent to the study's interpretive nature.

THEORETICAL FRAMEWORK: THE TRANSITION FROM HUMANISM TO POST-HUMANISM

Humans, dissatisfied with their current situation, have found themselves in a constant state of searching and innovation since their creation. Therefore, world history has witnessed many changes and developments. In this constantly evolving and changing world, technology, which entered our lives with the Industrial Revolution, has become almost indispensable in daily life. This progress, which has led to changes in every aspect of life, has enabled the formation of different social lives, cultures, and ideas. One of these ideas, which emerged as a result of differentiating human structures and social societies, is post-humanism. In the Encyclopedia of Art Terms, İslimyeli (1973) defines humanism as "a philosophical, scientific, and artistic view that emerged in the 14th century, taking ancient Greek and Latin culture as the highest example of culture and opposing the scholastic thought of the Middle Ages" (translated by the authors). The Merriam-Webster dictionary, in turn, defines the same term as "the revival of classical letters, individualistic and critical spirit, and emphasis on secular concerns characteristic of the Renaissance" (Merriam-Webster, n.d.).This view takes its name from the word "humanus," meaning humanity. Humanism, in general, is a philosophical movement that regards the rational human being as the sole and highest source of value, holds that the individual's creative and moral development can be achieved naturally, rationally and meaningfully without any recourse to the supernatural, and foregrounds human naturalness,

freedom and activity (Turkish Language Association, as cited in Temel, 2019). The concept of humanism, first introduced by a German scholar in 1808, is a Western concept in terms of its history, form, and usage. Humanism first emerged in Italy in the 14th century and had a major influence on the emergence of the Renaissance (Durgun, 2015).

While viewing the human being as an entity possessing free will and wholeness, and harbouring the potential for self-actualisation (Göka, 2009), humanism has developed a modern ethical framework that places the human being, and human happiness, at the centre, rather than God, and maintains a distance from supernatural explanations (Kayıntu, 2019).

While Mirandola, an early proponent of humanist thought, viewed the human being as an entity capable of shaping its own existence through choices and inclined to understand nature, Erasmus regarded human reason, culture, education, and free will as fundamental conditions for human development. The approaches of Montaigne, Petrarch, and Boccaccio also contributed to the evolution of the humanist perspective, centreing on the idea of the individual gaining an understanding of the self, one's own limitations, nature, and the universe (cited in Çelik, 2017).

Hayles (1999) discusses post-humanism not as the disappearance of the human being, but through questioning the liberal humanist understanding that defines the human being as an autonomous, body-independent, and privileged subject. This approach evaluates the relationships that humans establish with the material body, information and technological systems. Haraway's (1991) cyborg figure, on the other hand, opposes the certainty of the boundaries between human/animal, organism/machine, and physical/non-physical and shows that human identity is established within biological, technological, and social relations. In this direction, the post-humanist subject is not seen as a completed entity independent of nature and technology; it is considered a hybrid and relational formation that constantly transforms in its relationships with human and non-human actors. Similarly, Wolfe defines post-humanism through the questions and ways of thinking that arise when we can no longer stand to place the human being at the centre of knowing the world as an autonomous and rational being (Wolfe, 2009, as cited in Pollock, 2011).

Challenging the humanist approach that positions the human as a privileged and universal subject, Braidotti has developed a feminist and zoe-centric perspective that encompasses non-human beings. In this vein, she re-evaluates the human beyond the Vitruvian ideal, conceptualising post-humanism as a shared ecology grounded in the interdependence of humans, non-human beings, nature, and technology. Viewing post-humanism not merely as a negative crisis but as an opportunity to restructure human relationships with nature and the environment, Braidotti's notion that "we are in this together" emphasises that humans are not independent of other beings and that coexistence must be founded on mutual responsibility (Braidotti, 2019).

Post-humanism remains a subject of widespread debate today and is examined from many different perspectives. Within this framework, the theoretical framework of post-humanism is studied as critical post-humanism and philosophical post-humanism. Philosophical post-humanism is further evaluated under two separate headings: pessimistic post-humanism and trans-humanism (Table 1).

Table 1 brings together the various theoretical orientations of post-humanism within a general framework. This framework outlines the key areas of debate central to the study's analysis: the critique of anthropocentric thought, the relationships between humans and non-human entities, and the transformative and adverse effects of technology. The categories employed in the spatial analysis of the novel were determined within this general theoretical structure, in alignment with the research's focus on the human-nature-technology nexus. The 'Naming Problem' of the concept of post-humanism stems from the fact that many thinkers approach it differently. Tamar Sharon (as cited in Ağın Dönmez, 2014) categorised the concept of post-humanism into five different headings: radical, methodological, liberal, dystopian, and her proposed mediated post-humanism. Of these five headings, the common aspect of the mediated, methodological, and radical concepts is their anti-anthropocentric nature. Radical post-humanism is concerned with correcting the distance between humans and nature and addressing the distorted interpersonal identities within the context of developing and changing technology. Methodological post-humanism, on the other hand, instead of evaluating the post-human era, addresses the connections between humans and non-humans through technology.

Table 1. Theoretical Framework of Post-Humanism (Table created by the author based on their readings)

Post-Humanism Theoretical Framework	
The Naming Problem: Post-humanism is approached and evaluated differently by many thinkers. Tamar Sharon groups post-humanism approaches under five headings: radical, methodological, liberal, dystopian, and what she calls mediated post-humanism. David Roden divides it into speculative and critical post-humanism. Jamie del Val and Stefan Sorgner, on the other hand, propose the concept of meta-humanism.	Philosophical Post-humanism examines the ultimate state of human cognitive and physical development, and the scope and impact of technological, scientific, natural, and medical advancements in pursuit of this goal.
Critical Post-Humanism: Through its evaluation of Western humanist perspectives, it creates a new philosophical and social discourse on nature, technology, and human thought, arguing that these should not be separated from one another.	Pessimistic Post-Humanism: Argues that new technological advancements negatively impact the body's natural structure, and that biotechnological progress, particularly mechanization, will harm the human body.
	Trans-humanism: Defends that developing and advancing technology will positively impact the human body, extend life expectancy, and create a more beneficial world.

Mediated post-humanism shares common ground with the views of radical and methodological post-humanism. According to mediated post-humanism, "new subjectivities emerge through technology-equipped relationships, outside of the identities defined by modern discourses and dualities." Dystopian and liberal post-humanism, corresponding to philosophical post-humanism, discuss technological and scientific progress and the ultimate state of the human body. David Roden (2015) divides post-humanism into speculative and critical post-humanism, examining what the future might entail outside of the trans-humanist understanding. Jamie Del Val and Stefan Sorgner (2010) propose the concept of metahumanism, aiming to establish a link between critical post-humanism and trans-humanism. The theoretical framework of philosophical post-humanism is examined under two headings.

Pessimistic post-humanism argues that new technological developments negatively affect the changes occurring in the natural structure of the body, and that biotechnological progress, especially with mechanisation, will harm the human structure (Yeşilyurt, 2017; Ferrando, 2013).

The classifications summarised in Table 2 demonstrate that, despite sharing certain common characteristics, post-humanist categories highlight distinct types of relationships. In this study, radical post-humanism is associated with the weakening of the human-nature divide; mediated post-humanism with the establishment of this relationship through technology; methodological post-humanism with relational assemblages between human and non-human actors; critical post-humanism with interspecies coexistence and ecological responsibility; and pessimistic post-humanism with the adverse effects of technology on humans and space. This distinction has served as the basis for identifying the spatial counterparts of these theoretical classifications within the novel.

As a school of thought that extends humanism's approach to human self-perfecting through technological advancements, trans-humanism aims to enhance human physical and cognitive attributes via science and technology. Applications such as artificial intelligence, genetic coding, and nanotechnology are evaluated in terms of transcending biological limits and extending human lifespan (Demir, 2018). In this regard, trans-humanism views technological possibilities as tools that enhance existing human capacities and propel humanity to a more advanced stage (Balkan, 2015).

While trans-humanism and post-humanism converge in the importance they attribute to technology, they diverge in how they position the human being. Whereas trans-humanism focuses on enhancing physical and cognitive capacities, post-humanism questions the view of the human as a privileged, central subject, instead evaluating the human within the context of relationships established with nature, non-human entities, matter, and technological systems. Consequently, in post-humanist approaches, the concept of the "critical post-human" signifies a relational mode of existence established beyond anthropocentrism, rather than the idea of a technologically enhanced, superior human (Çelik, 2019).

This relational approach demonstrates that the body, ecology, and technology cannot be conceived independent of one another. The relationships bringing together human and non-human actors constitute a spatial continuum that extends from the body to the scales of the home, dwelling, school, street, and environment. In the Anthropocene era, environmental issues and climate change challenge the definition of space solely based on human needs, while highlighting the roles played by diverse living beings, technological systems, and environmental conditions in the formation of space. The concept of coexistence beyond anthropocentrism entails an eco-cosmopolitan approach that encompasses human responsibility towards other beings and the environment. Rooted in the interrelationship of cultural, social, and ecological systems, this framework embraces modes of shared existence that unite humans and non-human living beings within a collective "we" (Gündoğan, 2019). Similarly, Braidotti's approach, which addresses life, death, and zoe in conjunction, views the human not as positioned above ecological life, but as part of a broader continuum of existence (Braidotti, 2014).

While both post-humanism and trans-humanism treat technology as a shared arena of discourse, post-humanism does not posit technology as the primary vehicle for human enhancement. Instead, it interrogates how technology transforms the relationships among humans, society, nature, and non-human entities (Güvenç, 2020). The impact of this transformation on new living spaces, art, literature, and cultural production highlights the interdisciplinary nature of post-humanist thought. The manifestations of post-humanism in literary texts are examined in Section 2.2.

Post-Humanism Classification	Features	Theoretical Definition	General Characteristics of Post-Humanism
Radical Post-Humanism	It is anti-anthropocentric, emphasises the interconnectedness of humans and nature, and addresses the distorted identities of people through technology, encompassing social, techno-cultural, and historical critique.	The Naming Problem	Its scope encompasses both the humanities and social sciences, as well as the natural sciences; its zoe-centric nature, which is contrary to humanism, and its juxtaposition of humans, nature, machines, and technology, along with its 'we're in this together' subjectivity.
Methodological Post-humanism	The examination of the connections between humans and non-humans through technology includes social, techno-cultural, and historical criticism.		
Liberal Post-Humanism	It includes anti-anthropocentric, social, techno-cultural, and historical critique.		
Mediated Post-Humanism	It is anti-anthropocentric, embraces the interconnectedness of humans and nature, addresses the distorted identities of people and the connections between humans and non-humans through technology, and includes social, techno-cultural, and historical critique.		
Dystopian Post-Humanism	It debates about the effects of technological and scientific progress on the human body should be examined in light of social, techno-cultural, and historical critiques.		
Speculative Post-Humanism	It should address what the future-oriented approach may include.		
Meta-Humanism	The idea that the body can be enhanced through technology is discussed.		
Critical Post-Humanism	The common thread in the effects of technological, scientific, and medical advancements is the social and philosophical intertwining of nature and humanity in a shared existence.	Critical Post-Humanism / The Problem of Naming	
Trans-humanism	It includes the process of transforming humans into superhumans by leveraging science and technology to enhance their physical and cognitive abilities; supporting the use of high technologies such as artificial intelligence, gene coding, and nanotechnology on humans; human-centered and nature-centered.	Philosophical Post-humanism	
Pessimistic Post-Humanism	Human reproduction, eugenics, cloning, and genetic engineering are all movements involving the human body.		

Table 2. Classification and Characteristics of Post-Humanism (Table created by the author based on their readings)

Post-Humanism, Architecture, and Space

Post-humanist thought questioning the anthropocentric approach has led to a re-evaluation of the privileged and defining position of the human within design disciplines. The shift from a human-centred design philosophy to an ecological and ethical approach encompassing humans, nature, technology, and non-human actors demonstrates that design cannot be defined solely based on human needs (Duran and Pektaş Turgut, 2026). This intellectual transformation necessitates moving beyond the view of architectural space merely as a physical environment produced and used by humans.

Since its inception, architecture has evolved through interactions with diverse elements such as technology, the city, culture, non-human living beings, climate, the earth, and the environment alongside the human body and social life. Therefore, for architecture, post-humanist debates represent a re-evaluation of the complex relationships in which architecture has historically been embedded, rather than a completely new orientation (Sönmez, 2024). From a post-humanist perspective, architectural space is conceived as a relational environment formed by the mutual interactions of human and non-human actors, including humans, animals, plants, data, technology, materials, climate, and topography. Thus, architecture transcends being merely a formal and functional practice of

producing structures for humans; it acquires the character of a multi-species formation that organises the coexistence and interdependence of diverse entities (Yavaşi, 2025).

In terms of architectural and spatial theory, this approach views space not as a static, passive object shaped solely by humans but defines it as a dynamic formation continuously produced through relationships among humans, non-human living beings, technological systems, objects, materials, and environmental conditions(Akdeniz, 2025; Sönmez, 2024; Yavaşi, 2025). Foucault (1986) approaches contemporary space not as an empty and homogeneous medium, but as a heterogeneous structure shaped by relationships between distinct positions and elements. Regarding the theoretical approach of this study, this relational understanding of space can be linked to a post-humanist perspective that does not regard the human as the sole, independent centre of spatial formation, but rather makes visible the roles played by humans, technological systems, objects, and environmental elements in the constitution of space.

Kuran (2023) also views post-humanist space as a formation that evolves through relationships established with bodies, the environment, technology, and non-human entities. It is capable of adapting to diverse experiences and interacting with the broader ecosystem. In particular, cybernetic systems and extended reality technologies enable architecture to be redefined as a dynamic entity capable of communicating with its surroundings, adapting to changing conditions, and merging the physical with the digital (Karabağlı and Kuran Yıldırım, 2024). Accordingly, post-humanist architecture questions the rigid distinctions between human and nature, human and animal, physical and digital, and human and technology, thereby opening a discussion on the spatial manifestations of interspecies coexistence, ecological reciprocity, and hybrid modes of living.

According to Dalziel (2022), who critiques the anthropocentric tradition of architecture, architectural thought has long been shaped around the architectural object and its human user, while nature has been regarded merely as a resource and backdrop for human actions and well-being. In contrast, the post-humanist approach proposes rethinking architecture's modes of knowing and producing beyond the sole purpose of serving humans and expanding its scope of responsibility to encompass human and non-human, living and non-living earthly entities. From this perspective, post-humanist architecture is defined not merely by a technological or formal aesthetic, but by the relationships spatial practices establish among humans, nature, and non-human actors.

One approach that transcends the human-centric architectural paradigm is multispecies architectural design, in which non-human living beings are acknowledged as stakeholders in the design process. According to Grobman et al. (2023), multispecies design entails considering the spatial, environmental, and sensory needs of animals, plants, and other living beings alongside those of humans at the scale of the built structure. In this approach, architectural space ceases to be an environment shaped solely by the comfort and functional requirements of human users. Instead, it transforms into a shared living space where the needs of different species regarding shelter, movement, nutrition, protection, and coexistence are negotiated. However, key challenges within multispecies architecture include the potential conflicts arising between the needs of different species, the question of who represents these species during the design process, and the ethical valuesguiding spatial decisions. De-centering the human does not imply the complete exclusion of humans from the design

process; rather, it requires repositioning humans within broader ecological, material, and interspecies relationships (Nicenboim et al., 2025).

In this study, the post-humanist classifications outlined in the theoretical framework serve not merely as a conceptual background but as analytical tools for examining the novel's spatial construction. Based on the theoretical distinctions presented in Tables 1 and 2, the following were established as the primary criteria for analysis: the convergence of humans and nature, relationships mediated by technology, the spatial coexistence of human and non-human actors, interspecies symbiosis, and the adverse effects of technology. These criteria were translated into spatial indicators through the coding process described in the methodology section. Their manifestations within the novel are presented in Table 3.

Post-Humanism in Literature

Post-humanism is gaining traction in the fields of literature, art, cinema, and cultural studies as an interdisciplinary approach that re-examines the human relationship with nature, technology, and non-human entities. A significant portion of research in this area highlights themes such as the questioning of the anthropocentric subject, the return to nature, human-animal relations, the artificial human, bodily transformation, digitalisation, and the technological future. The literature review conducted for this study evaluates the papers from the "Posthumanism in Literature and Art" symposium organised by the Department of English Language and Literature at Istanbul University's Faculty of Letters as the 12th Akşit Göktürk Commemoration Meeting alongside other research examining the evolution of post-humanist literature.

The first major trend in the literature involves the examination of the return to nature alongside a critique of modern life and human-animal relationships from a post-humanist perspective. Köseman (2019) treats the return to nature in Ernest Hemingway's *Big Two-Hearted River* as a form of escape from and healing for the unrest caused by modern life, emphasising nature's transformative effect on the individual. By analysing the novel, *Motherland Hotel*, through post-humanist and eco-critical lenses, Artukarslan (2019) evaluates Zebercet's relationship with animals, specifically his objectification of them and the violence he inflicts upon them, by questioning the boundaries between humans and animals. Meanwhile, Koçsoy (2019) demonstrates that in Willa Cather's short story "Neighbour Rosicky," rural life is presented as an alternative to the problems wrought by industrialisation and modernisation, and nature is treated as an integral part of human existence. These studies reveal that nature is not merely a passive setting for the narrative; rather, it is an active element that participates in the characters' transformations, challenges the anthropocentric way of life, and reconfigures human/non-human relationships.

The second trend involves questioning human identity through the concepts of the artificial human, bodily transformation, and post-human existence. Adopting an anti-humanist approach to Mikhail Bulgakov's novel *Heart of a Dog*, Çağlayan (2019) examines issues of moral degradation and human identity through the lens of transferring human consciousness to another living being. Sunar (2019) traces the origins of post-humanist literature back to Romantic narratives, evaluating Olympia from E. T. A. Hoffmann's *The Sandman* and the nameless creature from Mary Shelley's *Frankenstein* through the theme of the artificial human. Demir (2019) questions humanity's place in the universe in Maggie Gee's novel *Light Years* by employing critical post-human theory and narratology. While Ayyıldız (2019) analyses the representation of the transition to a post-human society in Arthur C. Clarke's *Childhood's End*, Kasurka (2019)

addresses the digitisation of the human brain and body as well as various forms of digitisation within the context of post-humanism in Richard K. Morgan's *Altered Carbon*. Methodologically, these studies draw upon diverse approaches such as anti-humanist readings, critical post-human theory, narratology, and thematic textual analysis.

Another strand of post-humanist literature examines the social, political, and artistic representations of post-human thought. Taş (2019) analyses Aldous Huxley's novel Brave New World through the concepts of social stability, individual freedom, and eugenics, evaluating the hierarchical order of the "World State" in the novel by drawing on Homi Bhabha's concept of "ambivalence." Bayal (2019) discusses humanity's drift towards catastrophe within a post-humanist framework by linking Béla Tarr's film The Turin Horse to Nietzsche's concepts of the Übermensch (overman), eternal recurrence, and the will to power. Tutucu (2019) reads "The Universal Declaration of Human Rights" from an anti-humanist perspective using Derrida's method of deconstruction, while Çetin (2019) examines the decentreing of the human and the dehumanisation of performance in theatre and opera through the work Neither. Thus, it becomes evident that the post-humanist approach is employed to question the privileged position of the human not only in novels and short stories but also across diverse fields of representation such as legal texts, cinema, theatre, and opera.

The historical evolution of science fiction literature is also a significant source of post-humanist thought. Although it is difficult to pinpoint the exact date when post-humanist literature began, the concepts of human perfectibility and the transcendence of biological limits gained visibility in the 19th century through Mary Shelley's Frankenstein and the works of Edgar Allan Poe and Nathaniel Hawthorne. Meanwhile, H. G. Wells's The Time Machine and Olaf Stapledon's Last and First Men introduced new perspectives on the post-human future and time travel. The emergence of utopian, mechanised, and dystopian lifestyles, integrated with technology in literature, contributed to the development of the post-human concept in the West and the proliferation of post-human and trans-human themes in science fiction novels (Carretero González, 2016; Lake, 2013; Nutu, 2023; Sommerfeld, 2018; Vint, 2022).

Science fiction texts explore the impact of technology on human identity and existence through elements such as robots, cyborgs, mechanical spaces, virtual bodies, and artificial intelligence. In these narratives, humans and their environments do not always occupy fully realised, concrete spaces. Instead, the reader is invited to construct the narrative gaps within his or her own imagination. Science fiction authors make visible through literary texts future events, technological advancements, and spatial transformations (Dağ, 2018). Various forms of post-human existence appear in works such as Philip K. Dick's Do Androids Dream of Electric Sheep?, Octavia Butler's Fledgling, Walter M. Miller's A Canticle for Leibowitz, and P.D. James's The Children of Men, as well as in the works of Pat Cadigan and Angela Carter (Yılmaz, 2020; Buran, 2020).
The increasing role of technology in shaping human life has led to a shift in the definition of the human and the emergence of quests for new identities. Ihab Hassan's association of the concept of "post-humanism" with the human search for new identity paved the way for examining through new theoretical approaches how scientific and technological developments are reflected in literature and cinema (Özenç, 2019; Özmen & Vardar, 2019). Advances in science and technology, particularly during the 20th centuries, have fostered the development of science fiction literature and enabled the exploration of future scientific possibilities through the power of imagination (Altan, 1996).

Throughout this process, the concepts, symbols, and imagery of post-humanism have become increasingly prominent in science fiction literature.

When the reviewed literature is considered as a whole, three fundamental methodological orientations emerge: the theoretical reading of literary works through specific post-humanist concepts; the examination of human and non-human relationships via eco-critical or anti-humanist approaches; and the assessment of the impacts of technological transformations on the body, identity, and society through thematic textual analysis. However, existing research predominantly focuses on character, body, identity, technology, nature, and human-animal relationships, while the ways in which these relationships are reflected in the construction, use, and transformation of space are addressed to a more limited extent. Furthermore, there is a lack of systematic spatial analyses that comparatively apply different theoretical categories of post-humanism to the same work. Drawing on Ferrando's approach to philosophical post-humanism, Wilson and Jeevaraj (2023) propose that the components of post-humanism, post-anthropocentrism, and post-dualism can serve as a methodological framework for examining post-humanist discourses in literary texts. This study goes beyond merely applying the aforementioned literature to a new novel; it translates approaches such as radical, mediated, methodological, critical/zoe-centric, and pessimistic post-humanism into spatial indicators and employs them within a unified analytical framework.

Consequently, the study examines in conjunction themes, such as the retreat into nature, technological mediation, interspecies coexistence, the adaptation of domestic interiors to diverse user types, and the critique of the spatial pressures exerted by technology, all as presented in the novel *Bildiğimiz Dünyanın Sonu (The End of the World As We Know It)*. In this respect, the research presents a systematic analytical practice that examines body-, identity-, and nature-focused debates within post-humanist literary studies at the scales of architecture, space, and interior space by employing existing post-humanist categories in conjunction with spatial indicators.

ANALYSIS OF THE NOVEL, *THE END OF THE WORLD AS WE KNOW IT*, THROUGH THE LENS OF POST-HUMANISM

In this section, spatial segments of the novel are analysed by relating them to the categories of post-humanism defined within the theoretical framework. The segments, selected manually based on the criteria outlined in the methodology, are evaluated through close reading, taking into account their spatial contexts and their functions within the narrative as a whole. The subsections elucidate the relationships between the spatial indicators of the relevant categories and the novel's segments. The categories are employed not as mutually exclusive classes but as analytical tools capable of intersecting within the same space. Finally, the segments examined under the various categories are evaluated collectively to develop a holistic interpretation of the novel's post-humanist spatial construction.

Erlend Loe, the author of the novel *The End of the World As We Know It*, was born on May 24, 1969, in Norway. Before becoming a writer, he worked in a psychiatric clinic and later as a reporter for a newspaper. Loe's entry into writing was with his first novel, *Tatt av Kvinnen*, published in 1993. The author, who still lives in Oslo today, has books in various genres. He mostly uses irony, humour, and exaggeration in his works. Erlend Loe's novel used in this study is *The End of the World As We Know It*, a sequel to his 2004 novel *Doppler*. Of the three books in the series, *Volvo Lastvagnar* has not been translated into Turkish. Doppler is

both the main character and the driving force behind the novel (Wikipedia, n.d.-a; Wikipedia, n.d.-b).

In *The End of the World As We Know It*, the protagonist, Doppler, has distanced himself from modern life and everything associated with it, beginning a life in the forest. However, the plot begins with a sudden decision to leave his deer, Bongo, at a horned animal sanctuary and return to Oslo, driven by a longing for his family. Upon returning to the city, he expects his wife and children to have missed him, only to find the house he left painted blue, a political symbol of the time, and a different name on the mailbox. Contrary to his expectations, this disappoints Doppler. During his time in the forest, he forgot about modern life and his connections with people, becoming accustomed to a primitive existence. Upon returning to the city, although he initially faced many problems, he eventually managed to reconnect with his family. However, rejecting the obligations of city life, he felt he could not adapt to society, and his mental health gradually deteriorated. While dealing with social integration problems on the one hand, the novel also criticises the "consumer society" in which the character finds himself.

The book addresses the problems a character, detached from modern society, faces while trying to reintegrate into modern life, in a sexist, depressive, and absurd way. While transitioning between many different topics, the novel adopts a critical stance, criticising "modern society's self-created order, unnecessary life problems, and human efforts to adapt to the systemic order," and emphasises that problems will be resolved "by being in harmony with nature." In the novel, the reflections of post-humanism are not limited to space but also manifest themselves in the human body and the functioning of the system. In analysing the space in the novel, the following subheadings were created on the basis of the post-humanism classifications presented in the theoretical framework section (Chapter 2):

- A Hybrid Living Space at the Intersection of Nature and Technology (Radical and Mediated Post-Humanism)
- Ecological Infrastructure and Interspecies Symbiosis (Critical/Zoe-Centric Post-humanism)
- Technological Consumption and Spatial Resistance (Pessimistic Post-Humanism)
- Residential Interior Transforming Through Interspecies Use (Methodological, Mediated, and Critical Post-Humanism)

A Hybrid Living Space at the Intersection of Nature and Technology (Radical and Mediated Post-Humanism)

When Doppler first arrived in the city, he could not adapt to modern life and, seeing that his wife and children were living with someone else, he began living in the top of a tree. He also thought that he could easily observe them and their modern lives. Indeed, this is what happened as the novel progressed. Doppler, who began living in the top of the tree, eventually acquired a new generation tent, creating a space for himself. The effect of radical post-humanism here is that Doppler's living in the tree facilitates a rapprochement between humans and nature. From the perspective of mediated post-humanism, Doppler's life in the tree represents the intertwining of humans and nature, while the technologically advanced tent establishes a connection between humans and non-humans through technology.

"*After some interesting but in many ways impractical and less comfortable days spent in the pine tree, Doppler one day went down to the city center and stole*

a device called a tree tent. According to the easily deceived, polite seller, this tent was the best on the market, with its innovative central pole and the use of TG aluminum, which gave maximum strength relative to its weight. The aluminum was also anodized to provide corrosion resistance. Double-layered polyester fabric was used in all sensitive areas. Mountaineers used these kinds of tents when they needed to sleep suspended on the slope… Sleeping suspended on the slope? There you go. After a little effort, the tent hung up in the pine tree. It was also green, disappearing among the dense branches. Doppler thus moved to the top of the tree. He began to live there. 'I live in a pine tree,' he thought. 'That's the kind of person I am now'" (p. 32).

Ecological Infrastructure and Interspecies Symbiosis (Critical/Zoe-Centric Post-humanism)

While Doppler continued his observations in the tent where he lived, he saw that trucks carrying "pellets" were refueling the systems installed in the houses. Pellets are a renewable fuel created by grinding forest waste into sawdust and then compressing it under high pressure. With the transition from diesel to pellets as a new development, an environmentally friendly system is being used in spaces. From a critical post-humanist perspective, the novel focuses on communal living beyond anthropocentrism, addresses environmental problems and climate change through new forms of existence, and emphasises the responsibility people have towards each other.

"*Doppler became curious, climbed down from the tree, and started chatting with the pellet seller. 'Yes, the people in this house had switched from diesel to pellets two years ago. They received almost sixty thousand krona in aid from the municipality,' the pellet seller informed him; from what he heard, the system worked perfectly. Once or twice a year, he would come and fill the silo in the basement, built by the man of the house himself, with tons of pellets. This way, both the radiators and the water were heated almost entirely from renewable sources. Those who switched to pellets can shower all day for just a few krona,' said the pellet seller, beaming" (p. 37).*

The critical post-humanist approach, which exhibits a symbiotic relationship with nature and its offerings, can be seen in Loe's novel, The End of the World as We Know It, in the new space where Doppler and Bongo live together. Loe also employs a "zoe-centric approach" here, constructing a system that brings together humans and non-humans through the character of Doppler. This approach reveals that the novel explores the shared life of humans, nature, and non-humans within the context of this new spatial setting.

" Bongo and Doppler now lived on the top floor of a new building, one of the architectural masterpieces of Langelinie. On the terrace there was a counter-current pool in which both humans and animals could swim, and a canvas hammock strong enough to hold them both. " (p. 198).

Technological Consumption and Spatial Resistance (Pessimistic Post-Humanism)

The novel's protagonist, Doppler, having lived a primitive life far removed from modern life for a long period, is unable to adapt to modern life upon his return and begins to flounder. One weekend, after his wife leaves the house, he decides to gather and burn various electronic and technological devices, as well as furniture such as the dining table and sofa. This approach, which shows traces of pessimistic post-humanism, reveals the negative impact of technological advancements on people and spaces:

"*As soon as they left, he started gathering things. He went from room to room, throwing small and medium-sized items into the blue IKEA bag. He snatched the*

computer from the girl's hand and ran out of the room. Doppler returned and grabbed the cell phone as well. He shouted, 'I'm sorry, but this needs to burn!' He rushed into the kitchen; He bought the coffee machine, the griddle, the toaster, the electric mixer, the egg cooker, the bread toaster, and the battery-powered porridge mixer that Egil Hegel had given Solveig as a Christmas gift. His neighbor, who lived in the white house, helped him move the dining table" (pp. 140-141).

Residential Interior Transforming Through Interspecies Use (Methodological, Mediated, and Critical Post-Humanism)

In the later stages, Doppler leaves his home and establishes a new life for himself with his deer. In the novel, Doppler's life with his deer Bongo, who cannot detach himself from nature and animals, demonstrates the zoe-centric approach characteristic of post-humanism. From the perspective of methodological post-humanism and mediated post-humanism, the unconventional sense of shared living space established by the novel's protagonist, Doppler, manifests itself through the establishment of a connection between humans and non-humans, living in harmony with nature, and the fact that this is achieved through technology.

"Doppler bought Bongo a waterbed and filled his room with fresh grass. He built a table with one end at a height where people could sit and the other at a height where a moose could stand. He installed a toilet for moose in the apartment and hired an animal psychologist to domesticate Bongo. He put everything he had into it. He was in a good position to invest. His business was thriving, the apartment was bright and very spacious, the parquet was Danish, and every kind of amenity was available nearby. At last, Doppler's affairs were on track. He felt that he had come back to himself. Anything could happen. Somewhere in this big city, there might be a woman who would consider starting a family with me, he imagined." (p. 188).

These segments, examined under various categories, have been evaluated not as isolated examples, but as spatial patterns through which the novel constructs the interrelationships between humans, nature, technology, and non-human entities. The fact that a single space can harbour multiple post-humanist relationships demonstrates that rigid boundaries cannot be drawn between these categories. The intersections, contradictions, and architectural correspondences among these patterns are addressed holistically in the subsequent Findings and Discussion section.

FINDINGS AND DISCUSSION

In line with the categories defined in the theoretical framework and the coding criteria explained in the methodology section, the spatial segments in the novel have been examined in terms of post-humanist relationships. Table 3 summarises how the abstract definitions of the theoretical categories are mapped onto the spatial indicators and textual traces within the novel. These mappings form the basis for the interpretations, presented in the subsequent analytical discussion, regarding which post-humanist relationship is made visible by each specific space.

Figure 1 holistically illustrates the intersection of theoretical categories with the four fundamental spatial patterns identified in the novel. The model demonstrates that different categories can jointly contribute to explaining the same spatial pattern.
Within these patterns, mediated post-humanism is particularly prominent, as technology transcends being solely an element of modern urban life and

establishes a new subjectivity and life practice in the natural space. Doppler's inability to adapt to modern urban life, resulting in his living in a high-tech tent atop a pine tree, represents both a rethinking of the boundaries between humans and nature and the establishment of a new form of symbiosis with non-human entities (e.g., the deer Bongo). This space aligns with Tamar Sharon's approach to mediated post-humanism, which she defines as "new subjects equipped with technology, outside of modern discourses and dualities" (Ağın Dönmez, 2014). Furthermore, such "technological-wilderness" spaces ironically transform modern human dependence on technology, in line with Zennure Köseman's (2019) post-humanist reading of the escape to nature as a search for peace.

Table 3. Post-humanist Categories and Spatial Indicators in the Novel

Post-humanism Category	Theoretical Definition	Spatial Indicators	Textual Trace (Example from a Novel)
Radical Post-humanism	Rejecting anthropocentric thinking and eliminating the separation between humans and nature.	A retreat into nature; a break from city life; the blurring of the line between humans and nature; residing within nature.	Doppler moves away from modern life and begins living in the top of a tree (p. 32).
Mediated Post-humanism	The re-establishment of relationships between humans, nature, and technology through technological tools.	A nature space enhanced with technology; a relationship established between humans and non-human beings through technology; a hybrid habitat.	TG's aluminium-supported tent is set up on top of the pine tree, and Doppler begins to live there (p. 32).
Methodological Post-humanism	Analysis of relational networks and practical mechanisms between human and non-human entities.	Spatial practices that regulate human-animal interaction; new spatial mechanisms that organise daily life.	Doppler buys Bongo a waterbed, installs a toilet for moose, and builds a table that both humans and the moose can use (p. 188).
Critical Post-humanism (zoe-centric)	An approach that advocates for the coexistence of humans, nature, and non-human beings; developing an ecological and ethical perspective.	Interspecies symbiotic spaces; sustainable/ecological systems; non-anthropocentric way of life.	Switching from diesel to a pellet system supports environmentally friendly energy use (p. 37). The space where Doppler and his deer Bongo live together (p. 198).
Pessimistic Post-humanism	An approach that focuses on the negative impacts of technological advancements on people and environments.	Technological objects invading space; reactions against technology; critique of modern life and subversive actions.	Doppler collects and burns the technological devices and belongings in the house (pp. 140-141).

As shown in Table 3, the categories have not been treated as mutually exclusive classes. The association of a single spatial segment with multiple categories demonstrates that the post-humanist relationships in the novel are intertwined and that the categories offer distinct analytical dimensions.

The findings indicate that the spatial configuration of the novel is shaped by four fundamental patterns: the withdrawal from the city to nature; hybrid living spaces formed through the convergence of nature and technology; interspecies coexistence between humans and animals; and a critique of the spatial impacts of modern technology. These patterns constitute the novel's manifestations of the relational concept of space defined within the theoretical framework.
When considered within the context of critical post-humanism, the emphasis on renewable fuel spaces like the "pellet system" in the novel parallels Braidotti's (2019) zoe-centric perspective. The author views technology not only as a destructive force but also as a potentially healing one, demonstrating the sustainability of interspecies life through a spatial construct. In this context, the shared space that Doppler establishes with the deer Bongo is a reflection not only of the "animal-human" relationship but also of post-humanist ethics.

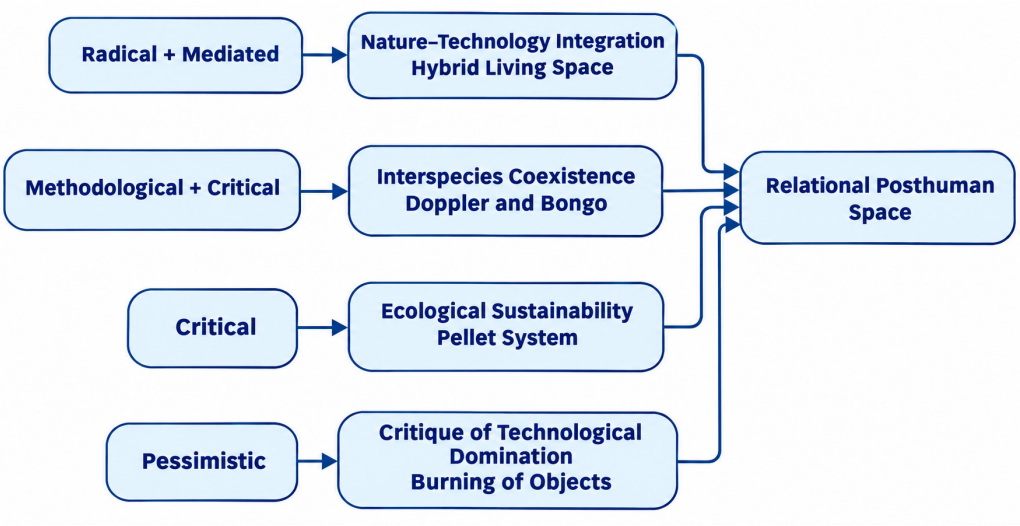


Figure 1. Relational Model between Post-Humanist Categories and Spatial Patterns in the Novel (Created by the author).

On the other hand, the scene of "burning technological objects" in the novel can be read as a rebellion against the hegemonic influence of modern technology on humanity from a pessimistic post-humanist perspective. As Ferrando (2013) points out, biotechnological progress may not always be liberating. Nowadays, spaces sometimes cause individuals to remain bound to materials identified with excess. Loe's incorporation of this critique into his novel through humour and a disquieting narrative style evokes the discourse of anti-technology dystopias.

Implications for Architecture, Interior Design, and Design Education

The findings indicate that literary space can be understood not merely as a physical backdrop where events unfold, but as a relational structure wherein relationships among humans, nature, technology, and non-human actors are established and transformed. This approach contributes to questioning the prevailing view in architectural and spatial studies that regards the human as the sole user and determinant of space. The patterns of integration with nature, technological hybridisation, and interspecies coexistence identified through the novel offer a conceptual perspective for evaluating spatial formation through the mutual interaction of diverse living, technological, and environmental components. When viewed through the lens of sustainability, the findings demonstrate that environmental sensitivity cannot be confined to technical matters such as energy efficiency and the use of renewable resources. A post-humanist understanding of space addresses sustainability within a broader ethical and ecological framework. It is one that extends beyond merely mitigating human impact on the environment to encompass the needs of non-human living beings, natural processes, and interspecies interdependencies. In this regard, the study's findings can be linked to contemporary architectural discourses concerning multispecies living, ecological reciprocity, and non-anthropocentric design approaches.

Some spatial patterns manifest at the scale of the residential interior. Household technological devices, furniture, energy infrastructure, and arrangements designed for multispecies coexistence demonstrate that the interior is not merely a passive environment shaped solely by human needs. In the apartment shared by Doppler and Bongo, the installation of a waterbed and toilet for the deer, the arrangement of the room with fresh grass, and the design of the table at two different heights to accommodate varying body sizes reveal that functions related to furniture, hygiene, rest, and shared use have been re-evaluated to meet the needs of a non-human user. Thus, the residential interior transforms

from a standard layout where the human is regarded as the sole user into a shared space that supports an interspecies' everyday life.

Spatial adaptations made to suit Bongo's physical needs render the non-human user's presence within the domestic interior visible. These arrangements can be linked to a multi-species architectural approach that advocates for incorporating the spatial and physical requirements of non-human beings into design decisions at the building scale (Grobman et al., 2023). However, the fact that these needs are interpreted by Doppler and that spatial decisions are made by a human subject demonstrates that the process of decentreing the human is not a completed state. Nicenboim et al. (2024) note that decentreing the human through design should be viewed not as a definitive outcome, but rather as a practice in which the designer continuously questions his/her own position and anthropocentric assumptions. In this light, the shared living space of Doppler and Bongo is not a place where anthropocentrism has been entirely eliminated; rather, it is a contradictory environment where the dynamics of representation, decision making, and spatial power relations between the human and the non-human are constantly renegotiated.

The integration of the pellet system connecting the basement silo, radiators, and hot water system demonstrates that the post-humanist transformation extends beyond furniture and usage arrangements to the interior's technical infrastructure. Conversely, the burning of electronic devices and furniture makes visible the decisive impact of technological equipment on daily life, consumption habits, and the space itself. When these findings are considered together, the interior emerges as a dynamic structure reconfigured through relationships involving the body, functions, furnishings, technology, energy, and interspecies usage. The study's overarching spatial framework thus links interior architecture with the themes of user diversity, function, and technical infrastructure.

The practical value of this study for architectural and design education lies in the potential to use literary narratives as tools for thinking and analysis that open up discussions on alternative spatial relationships. The post-humanist spatial reading framework developed in the study can be applied to questioning human nature, human-animal, and human–technology relationships in design studios, developing usage scenarios that encompass diverse actors, and debating spatial proposals that integrate nature and technology. However, these insights should be viewed not as directly applicable design criteria, but rather as a conceptual and critical framework for architectural research and design education.

Contradictions and Limits of Post-Humanist Space

When the findings are considered together, it becomes evident that the novel's construction of post-humanist space does not present a wholly harmonious coexistence among nature, technology, and non-human entities. The fact that Doppler uses a high-tech tent while living in a tree despite having withdrawn from modern urban life demonstrates that a return to nature does not signify a complete break from technology. Here, technology is both a component of the modern order being criticised and the means that enables the creation of an alternative living space within nature. This dual position reveals that mediated post-humanism in the novel does not merely generate a new subjectivity supported by technology, it also perpetuates human dependence on the very systems being opposed.

A similar tension is evident in the shared living space of Doppler and Bongo. Reconfiguring the space to suit a deer's physical and daily needs renders the

spatial presence of a non-human user visible. However, the fact that Doppler dictates all these arrangements calls into question the egalitarian nature of this interspecies coexistence. Although Bongo is acknowledged as a user of the space, he does not become an agent of spatial decision making. Instead, he is incorporated into a usage scheme defined by the human. Consequently, the shared life depicted in the novel presents a spatial experience where the power dynamic between human and non-human is renegotiated, rather than a model that entirely transcends anthropocentric design. These spatial adaptations can be viewed as the interior space counterpart to the multi-species architectural approach as described by Grobman et al. (2023), which integrates the needs of non-human beings into design decisions at the scale of the structure.

The contrast between the pellet system and the burning of technological objects reinforces the novel's ambivalent attitude towards technology. While the pellet system illustrates the aspect of technology that supports environmental sustainability, the burning of household appliances represents a reaction against the pressure that some technology exerts on consumption habits and daily life. However, the destruction of these objects does not offer a viable or sustainable alternative to the relationship established with technology. Consequently, rather than presenting a consistent model that either wholly affirms or rejects technology, the novel highlights the tension between technology's ecological potential and its social and spatial pressures. These contradictions demonstrate that post-humanist categories should not be employed as definitions that sort segments of the novel into rigid, immutable classes. Instead, these categories function as analytical tools that reveal the diverse and, at times, conflicting relationships existing within the same space. The distinctiveness of the novel's spatial configuration stems not from its presentation of a resolved harmony among nature, technology, humans, and non-human entities, but rather from its exposure of the interdependencies, inequalities, and contradictions inherent in these relationships.

CONCLUSION

This study examines the spatial configuration in Erlend Loe's novel, *The End of the World As We Know It,* through the lenses of radical, mediated, methodological, critical/zoe-centric, and pessimistic post-humanism. The findings indicate that the spaces in the novel are not direct or independent examples of these categories. Rather, they are shaped by the fluid, intersecting, and, at times, contradictory relationships among humans, nature, technology, and non-human entities. Consequently, these categories are treated not as fixed classifications used to demonstrate that the text validates specific theoretical perspectives, but as analytical tools that render visible the relationships, contrasts, and ambiguities within the novel.

The study's fundamental contribution to post-humanist theory is its demonstration that anthropocentrism is not eliminated simply by incorporating non-human entities into narratives and spaces. Post-humanist relationships such as interspecies coexistence, technological mediation, and environmental sensitivity can perpetuate the human position as decision maker and maintain human dependence on technology in various ways. In this regard, post-humanist space is best understood not as a completed, harmonious order among humans, nature, and technology, but rather as a relational formation in which the positions, dependencies, and responsibilities of diverse actors are constantly being negotiated. Thus, the study approaches post-humanism not as an ideal state that has been achieved, but as a critical field of inquiry characterised by inherent ethical, technological, and spatial tensions.

From the perspective of literary criticism, the research demonstrates that post-humanist narratives can be examined not only through representations of characters, bodies, identities, and non-humans but also through the spatial arrangements that participate in the formation and transformation of these relationships. Regarding spatial theory, the study concludes that literary space is not merely a passive background accompanying the narrative; rather, it is an active component that organises the relationships among bodies, technological objects, energy systems, environmental conditions, non-human entities, and everyday practices. The study's original contribution lies not in proposing a new post-humanist theory or method, but in establishing a systematic analytical link between literary text analysis and research in architecture and interior design by operationalising existing post-humanist categories through spatial indicators. From the perspective of architecture and interior design, this analytical connection enables a discussion of general spatial relationships at the residential scale encompassing furniture, fixtures, energy, infrastructure, the body, and the diversity of human and non-human users, thereby demonstrating that the interior is not merely a physical environment shaped by human needs. However, the inferences drawn from this study should be regarded not as directly applicable design criteria, but rather as a conceptual and critical framework for examining the relationships among humans, non-human entities, technology, and environmental systems within the fields of architecture and design.

The fact that the study is limited to a single novel restricts the generalisability of the findings to other literary works and contexts. However, focusing on a single work has enabled an in-depth examination of the spatial patterns and theoretical contradictions within the novel. Another limitation is that the coding and interpretation process was conducted by a single researcher, meaning the interpretations could have been influenced by the researcher's theoretical stance. Furthermore, as the analysis is based on the Turkish translation of the novel, it is acknowledged that the translator's lexical and semantic choices may have influenced the interpretation of the spatial narrative.

In future studies, the analytical approach employed in this research could be applied to various literary texts to conduct comparative analyses. Research examining texts in their original language alongside their translations could reveal the impact of linguistic choices on post-humanist spatial representations, while collaborative studies involving multiple researchers could comparatively assess the consistency of the coding process. Furthermore, the potential application of post-humanist spatial scenarios derived from literary narratives within architectural design studios could be explored. Visualising these spaces using generative AI tools and examining the alignment of the visual outputs with the spatial relationships described in the text could also establish a new field of inquiry bridging literary spatial analysis and AI-assisted architectural representation.

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Research Article

Process and Cost Implications of HBIM in Project Management: A Comparative Study of Projects in Türkiye and International Contexts

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Abstract

The documentation, conservation, and sustainable management of cultural heritage buildings are increasingly addressed through digital technologies. In this context, Heritage Building Information Modelling (HBIM) provides a strategic approach that supports not only the geometric representation of historic structures but also the integrated management of project processes in terms of time and cost. This study aims to evaluate HBIM applications from a project management perspective, focusing on their effects on schedule and cost efficiency. The research is based on a comparative analysis of 20 HBIM projects conducted in Türkiye and abroad, examining data acquisition methods, software usage, modelling workflows, and project durations. A qualitative research methodology was adopted, and data were obtained from academic journal articles and postgraduate theses using content analysis and comparative evaluation. The findings indicate that HBIM significantly improves project efficiency by supporting time and cost control while strengthening data integrity and coordination among stakeholders. Accordingly, the study emphasizes that HBIM should be considered not only as a digital documentation method but also as an effective project management tool in cultural heritage projects.

Keywords: Cost Management, Cultural Heritage Buildings, HBIM, Project Management, Time Management.

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INTRODUCTION

HBIM (Heritage Building Information Modelling) has become an increasingly important approach in the documentation, conservation, and management of cultural heritage structures. Unlike traditional methods, it allows historic buildings to be represented with a high level of accuracy while also supporting decision-making processes in restoration projects. By combining technologies such as laser scanning, photogrammetry, and 3D modelling, HBIM makes it possible to capture both the geometric and structural characteristics of heritage buildings in a more comprehensive way.

In addition to its technical advantages, HBIM also contributes to improving project processes. It supports faster planning, reduce potential errors, and enhance coordination among different stakeholders involved in conservation work. This makes it particularly valuable in complex restoration projects where multiple disciplines need to work together.

However, despite these benefits, the application of HBIM is not without challenges. The complex nature of historic structures, limitations in available data, and the relatively high cost of digital technologies can make the process difficult to implement in some cases. For this reason, evaluating HBIM not only as a modelling tool but also as a practical solution within project management becomes essential.

THE AIM OF THE STUDY

The main aim of this study is to examine HBIM applications in cultural heritage projects from a project management perspective, with a particular focus on time and cost efficiency. Within this scope, 20 HBIM projects carried out in Türkiye and in various international contexts were analysed comparatively.

Rather than considering HBIM solely as a tool digital documentation, this study also examines how it supports project workflows.

By analysing different case studies, it demonstrates how HBIM helps reduce data loss, improve stakeholder communication, and facilitate decision-making during conservation and restoration projects.

In this context, the study also aims to highlight the potential of HBIM as a strategic tool that can strengthen both the technical and project-related aspects of cultural heritage projects.

SCOPE AND METHODOLOGY OF THE STUDY

This study is qualitative research that aims to examine the effects of HBIM applications on time and cost management within the scope of project management. This research, 20 HBIM studies identified through a comprehensive literature review from Türkiye and various other countries were comparatively analysed.

The data were obtained through an academic literature review using the key concepts of HBIM (Heritage Building Information Modelling), digital documentation, historic structures, and project management. The selected studies were evaluated according to their relevance to the research focus and their ability to provide comparable project-related data, such as project duration, workflow stages, software use, data collection techniques, and other

measurable outputs related to time and cost management. Therefore, the cases were selected not only because they addressed HBIM, but also because they provided sufficiently explicit information for comparative evaluation from a project management perspective.

Since the study aims to provide a balanced comparison between HBIM applications in Türkiye and other countries, the sample was limited to 20 case studies, including 10 from Türkiye and 10 from other countries. This number was considered sufficient to maintain analytical clarity and consistency across the selected cases. A limitation of the study is that accessible and comparable HBIM studies in Türkiye remain relatively limited, as the field is still developing. For this reason, the selection of Turkish cases was shaped by both relevance to the topic and the availability of sufficiently detailed case-based data.

Based on these research questions, the methodological framework followed in the study was developed systematically and is illustrated in Figure 1. For the comparative analysis, evaluation questions were determined during the early stages of the literature review in order to examine the effects of HBIM applications on efficiency, process management, and software. During the literature review process, it was observed that the defined research questions showed similarities with the analytical themes used by Bastem (2021). This finding indicates that the study is theoretically and methodologically grounded in a framework consistent with recent studies in the literature. The information obtained through the literature review was classified under the themes of "data collection method," "software preference," "the contribution of plugins to the project process," and "the relationship between data accuracy, time, and cost." These themes were compared with HBIM process analyses found in the literature, and common evaluation criteria were established for each project. Thus, similarities and differences related to time and cost management in HBIM processes implemented in different countries were identified.

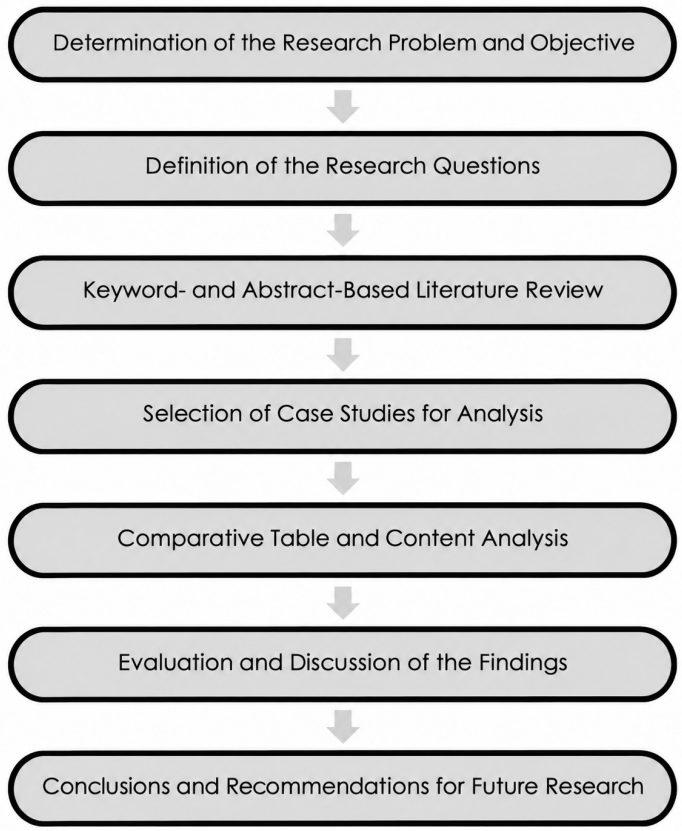


Figure 1. Methodology of the Study (created by the author)

The evaluation questions determined within the scope of the study are as follows:
1.Which techniques have been used as data collection methods in HBIM applications?
2.To what extent are the software tools used suitable in terms of the scale and design requirements of the project?
3.Which plugins were used with the software, and what contributions did they make to the project process?
4.What is the impact of the selected data collection method on data accuracy?

CONCEPTUAL FRAMEWORK ON HBIM AND DOCUMENTATION TECHNIQUES

Cultural heritage structures are unique assets that embody the aesthetic, technological, and social values of past civilizations to the present day. The documentation, conservation, and sustainable management of these structures have become major areas of research within the field of heritage conservation since the late twentieth century. As traditional documentation methods proved insufficient for capturing the complexity of historic structures, digital technologies have introduced new possibilities. In this context, the concept of HBIM emerged through the adaptation of Building Information Modelling (BIM) systems to historic buildings. HBIM enables not only the three-dimensional documentation of structures but also the integration of material characteristics, intervention histories, and restoration data into a comprehensive digital environment.

The conceptual framework is organized under four main headings: "The Emergence of the HBIM Concept," "HBIM Dimensions," "HBIM Development Levels," and "Methods and Techniques Used for the Documentation of Cultural Heritage".

The Emergence of HBIM

Building Information Modelling (BIM) emerged in the 1980s as part of the digital transformation in the construction sector and became widely adopted in the 2000s as technology improved (Succar, 2009). The primary objective of BIM is to create an integrated digital data environment that encompasses the entire lifecycle of a building, including design, construction, operation, and maintenance processes Toldo, 2016). However, the irregular geometries, unique material textures, and documentation deficiencies of historic structures fall outside the scope of standard BIM systems. Because of these challenges, the need for a more flexible system became clear, which led to the development of HBIM (Karaoğlu, 2020).

The development of HBIM has accelerated particularly after 2010 due to advancements in laser scanning, 3D photogrammetry, and sensor-based data acquisition technologies. These technologies have eliminated the limited accuracy issues associated with traditional photogrammetry and manual measurement methods, providing the opportunity for highly accurate digital documentation (Yılmaz et al., 2007). In this respect, HBIM has become a data-driven conservation method that enables the comprehensive digital transfer of the physical, historical and material characteristics of historic structures.

Dimensions of HBIM

BIM, as an information system, is not limited to three-dimensional geometric models; rather, it is a multidimensional system enriched with additional layers such as time, cost, energy, sustainability, and management (Jongeling, 2008). In HBIM, these dimensions extend beyond the documentation of cultural heritage and enable data-driven decision-making processes for conservation and intervention strategies.

- 3D (Geometric Model): Represents the physical form of the structure.
- 4D (Time Dimension): Connects project processes with time.
- 5D (Cost): Supports cost estimation and control.
- 6D (Energy Performance): Focuses on energy performance and efficiency.
- 7D (Facility Management): Relates to maintenance and long-term use of the building (Odabaşı, 2022).

Additionally, in cultural heritage–oriented HBIM models, specific dimensions defined by Castellano-Roman and Pinto-Puerto (2019) are also considered:

- 4B (Historical Development): Shows different historical phases of the structure.
- 5B (Identification): Defines the cultural identity of the building.
- 6B (Cultural Context): Includes information about the surrounding environment.
- 7B (Conservation and Intervention): Focuses on restoration and conservation processes.

Levels of Development of HBIM

In HBIM processes, the accuracy and level of detail of the model are critical. The concept of LOD (Level of Detail/Development) is used to describe the amount of information contained in a model and its reliability that information is for different stages of a project (Graham et al., 2018). This concept was developed to manage expectations among project stakeholders and to clarify the level of precision and reliability of the data contained within the model at different stages of the project (URL-2).

Globally accepted LOD standards vary according to regional and institutional approaches. In the system developed by the American Institute of Architects (AIA) and the Associated General Contractors of America (AGC), which is widely adopted in the industry, a numerical scale ranging from LOD 100 to LOD 500 has been adopted (URL-2). According to this classification:

- LOD 100 (Conceptual Design): Represents the basic form, location, and orientation of the structure.
- LOD 200 (Schematic Design): Includes approximate dimensions and general shapes.
- LOD 300 (Design Development): Elements are modeled with more accurate dimensions and positions.
- LOD 350 (Construction Documentation): Connections between building components are defined more clearly.
- LOD 400 (Fabrication and Assembly): Contains detailed information required for production and construction.
- LOD 500 (As-Built Condition): The final model containing the actual data of the structure after construction, used primarily for facility management (URL-2).

In contrast, practices in the United Kingdom adopt a different process-oriented approach. In the UK-based system, development levels are addressed in seven stages covering the entire life cycle of the building: LOD 1 (Brief), LOD 2 (Conceptual), LOD 3 (Developed Design), LOD 4 (Production), LOD 5 (Installation), LOD 6 (As-Built), and LOD 7 (Operation and Maintenance) (URL-2).

The LOD concept is generally classified within ranges such as LOD 100–500 or LOD 0–7 and indicates the level of detail contained in the model. In the context

of HBIM, however, these levels have been redefined for existing structures according to the accuracy of available data and the documentation methods employed (Chow et al., 2019):

- LOD 0: Elements may not be modeled; the structure may be represented only through point clouds or historical drawings.
- LOD 1: Shows the general form of the structure without detailed material information.
- LOD 2: Includes basic material and graphical representation.
- LOD 3: Provides more accurate geometry and partial material information.
- LOD 4: The model contains all details, including connections and element dimensions, and is used for areas requiring high accuracy.

These development levels determine the accuracy, reliability, and usability of the model in HBIM applications. Since HBIM studies are conducted based on the existing conditions of historic structures, LOD in this context defines not only the level of geometric detail but also the degree of integration of historical and material information within the model.

Methods and Techniques Used in The Documentation of Cultural Heritage

The conservation of cultural heritage and its transmission to future generations require the accurate identification of the geometric, physical, and material characteristics of structures. The documentation process is a technical activity carried out to determine the current condition of a structure, monitor its historical transformation, and provide a basis for future restoration projects (Aydın, 2024; Korumaz et al., 2011). The methods used in this process have evolved from traditional techniques toward digital and autonomous systems in parallel with technological developments.

Traditional documentation methods: Traditional documentation refers to the method in which the physical characteristics of historic structures are measured using simple hand tools such as measuring tapes, distance meters, plumb lines, and spirit levels, and the obtained data are transferred to hand-drawn sketches. This method represents the oldest and most fundamental approach in the history of architectural documentation (Aydın, 2024). In survey studies conducted using traditional methods, the plans, sections, and elevations of a structure are represented on a two-dimensional plane. However, this approach is insufficient in providing a comprehensive three-dimensional representation of the building (Aydın, 2024). Moreover, because it relies heavily on human intervention, it is prone to measurement errors, the process is highly time-consuming, and difficulties arise in accurately representing complex geometric forms such as muqarnas or highly ornamented surfaces (Aydın, 2024; Korumaz et al., 2011).

Digital documentation techniques: With the advancement of technology, documentation studies have shifted toward digital systems that do not require physical contact with the object and are capable of collecting highly accurate data in a relatively short time (Aydın, 2024). Digital documentation enables the production of simplified yet comprehensive models of cultural heritage assets that include not only their geometry but also texture and color information (Korumaz et al., 2011).

Topographic and geodetic measurements: This method, which can be considered the digitalized form of classical surveying techniques, employs devices such as total stations (electronic tacheometers). These instruments precisely determine the three-dimensional coordinates (X, Y, Z) of specific

points on a structure, thereby establishing the infrastructure for digital mapping (Korumaz et al., 2011). It is generally used as a complementary technique in photogrammetric studies to determine the coordinates of ground control points (GCPs) and to ensure that the model is accurately positioned within a real-world coordinate system (Aydın, 2024).

Photogrammetry: Photogrammetry is a technique that enables the acquisition of reliable metric data from overlapping photographs of objects or terrains taken from different angles (Aydın, 2024; Korumaz et al., 2011). Meaning "measurement through light," photogrammetry is one of the most widely used methods in the documentation of cultural heritage (Aydın, 2024).

Terrestrial Photogrammetry: This method is used in situations where images can be captured from close range, such as building façades or architectural details (Aydın, 2024). Particularly with the use of the "Structure from Motion" (SfM) technique, sequentially captured photographs can be processed to generate three-dimensional point clouds, solid models, and textured models of objects (Aydın, 2024). Compared to laser scanning, this method is more cost-effective and faster, while also offering advantages in visual documentation due to its ability to provide high-resolution texture data (Aydın, 2024).

Aerial Photogrammetry (UAV): This method, carried out using Unmanned Aerial Vehicles (UAVs), is effective for documenting areas that are difficult to access from the ground, such as roofs, domes, or extensive archaeological sites (Aydın, 2024). The data obtained through UAVs can be used to generate Digital Elevation Models (DEM) and large-scale maps (Aydın, 2024).

Terrestrial Laser Scanning (TLS based on LiDAR technology): Terrestrial Laser Scanning (TLS) is an active remote sensing method that uses Light Detection and Ranging (LiDAR) technology, in which laser pulses are emitted toward an object and the reflected signals are used to calculate distances (Aydın, 2024). This technology produces a dense and highly accurate three-dimensional representation of a structure, known as a point cloud, by collecting millions of point measurements per second (Aydın, 2024). Laser scanning is considered one of the most reliable methods for documenting complex structures, as it can operate even in low-light conditions and provides geometric data with millimetric accuracy (Aydın, 2024; Korumaz et al., 2011). However, the large volume of data generated and the high hardware requirements for processing constitute significant disadvantages of this technique (Aydın, 2024).
LiDAR, which possesses high-precision measurement capabilities, can generate a complete and highly accurate three-dimensional representation of objects; therefore, it provides highly reliable data for short-range remote sensing and photogrammetric studies (URL-1). Recent technological developments have enabled the integration of LiDAR sensors into mobile devices such as the iPhone 12 Pro. Currently used primarily for design-oriented applications, these mobile sensors are capable of generating three-dimensional models of environments within a range of approximately five meters and allow users to make real-time modifications to these models (URL-1).

Orthophoto: An orthophoto is an image obtained from photogrammetric photographs that have been geometrically corrected to eliminate tilt errors and perspective distortions, resulting in a true orthographic projection. This technique combines the visual richness of photography with the geometric accuracy of mapping (Aydın, 2024). In cultural heritage projects, orthophotos are commonly used as a base layer for façade surveys and for documenting complex surface details such as stone ornaments. Through orthophotos, it becomes possible to

perform scaled and precise drawings directly over photographs within CAD-based drawing software (Aydın, 2024).

HBIM APPLICATIONS IN TÜRKİYE AND ABROAD

Today, awareness of BIM is steadily increasing. This situation has accelerated the transition toward the use of BIM technology in historic structures as well. The concept of HBIM continues to evolve and has gained momentum in conservation and documentation studies over the years, leading to a gradual increase in its application. This development reflects the growing interest in digitalization, modelling, and technological innovations. Within this context, documentation studies conducted using HBIM in Türkiye and abroad—particularly in Italy—are discussed.

Italy possesses pioneering applications and a strong academic infrastructure in the field of HBIM and has produced numerous high-quality studies, especially on monumental structures such as churches, cathedrals, and fortifications. In Türkiye, HBIM applications are primarily developing at the academic level; although field implementations remain limited, the approach is gradually gaining wider attention and adoption.

HBIM Applications in Türkiye

HBIM (Heritage Building Information Modelling) applications in Türkiye are predominantly limited to theses, pilot projects, and individual studies conducted mainly at the academic level. However, the increasing awareness of digitalization in the fields of architecture, archaeology, and restoration in recent years has created an important foundation for the integration of HBIM into cultural heritage management processes in Türkiye. Within this framework, HBIM applications have been examined through several case studies located in Türkiye, as well as one example of Turkish origin located in Serbia, as presented in Table 1.

The effect of software on historical building information modelling: Abdal Musa Tomb

This example was evaluated using the data obtained from the study by Coşgun (2022). The research focuses on the Abdal Musa Tomb located in the district of Elmalı (Antalya) and aims to examine the effects of different software tools and modelling techniques on accuracy, time efficiency, and overall productivity within the Heritage Building Information Modelling (HBIM) process. During the data acquisition phase, the structure was documented using the photogrammetry method; hundreds of photographs were captured using drones and high-resolution cameras. These photographs were processed in Agisoft Metashape software to generate a dense point cloud and mesh surface model, which was subsequently cleaned and aligned using Autodesk ReCap (Coşgun, 2022). The processed data were then transferred to the Autodesk Revit environment, where the building components were modelled parametrically. During the modelling stage, the Dynamo plugin was employed to apply algorithmic definitions for parts with irregular geometries. The study indicates that while an inventory at the HBIM model at LOD 300 can be produced within a limited timeframe, the survey, restitution, and restoration processes require significantly more time (Coşgun, 2022).

A proposed approach based on the hbim methodology in the reconstruction process of digital heritage

This example was evaluated using the data obtained from the study by Yörük (2025). Through the case of the Nero Bath in the ancient city of Patara, it

Table 1. HBIM Projects in Türkiye (created by the author)

Case Study		Comparison Criteria			
Study Name	**Location**	**Data Collection Method**	**Suitability of the Software Used**	**Plugins Used and Their Contribution to the Project**	**Project Scale**
Abdal Musa Tomb (Coşgun, 2022)	Antalya	Photogrammetry drone imagery	Agisoft Metashape, ReCap, Revit, Dynamo	Dynamo: Creation of complex forms through algorithmic modelling when parametric modelling is insufficient	Structure (religious building tomb)
Patara Ancient City (Yörük, 2025)	Antalya	LiDAR scanning, drone photogrammetry	Agisoft Metashape, ReCap Pro, Rhinoceros, Revit, Navisworks	Autodesk Navisworks: Integration of different data sources, clash detection, 4D time planning, visualization of reconstruction scenarios	Structure (archaeological remains)
Ferdane Hanım Mansion (Garip, 2023)	Kocaeli	Laser scanning	ReCap Pro, Revit, Enscape	Enscape: Testing lighting, materials, and spatial perception in a 3D environment	Structure (building)
Afyonkarahisar Ulu Mosque (Tunay, 2022)	Afyon	Manual measurements, laser scanning	Trimble Realworks, ReCap, Faro Scene, Revit, Archicad	—	Structure (religious building – mosque)
Aya Yorgi Church (Günay, 2025)	Isparta	Laser scanning, photogrammetr, archival documents	Faro Scene, ReCap, Revit, Enscape	Enscape: Testing lighting, materials, and spatial perception in a 3D environment	Structure (religious building – church)
Pertev Paşa Mosque (Çelik, 2023)	Kocaeli	Laser scanning	ReCap, Revit	—	Structure (religious building – mosque)
Erythrai (Ildır) Archaeological Site (Sarıcaoğlu, 2021)	İzmir	Laser scanning, photogrammetry (175 min)	BIM environment	ICP (Iterative Closest Point) algorithm used for aligning point clouds	Structure (archaeological remains)
Mehmet Ağa Mansion (Odabaşı, 2022)	Ankara	Laser scanning (13.5 hours)	Faro Scene, ReCap, Revit (point cloud processing: 6 hours)	—	Structure (building)
Mahmud Pasha Bath (Çügen, 2022)	Serbia	Laser scanning, photographs, and videos	WebShare2Go, ReCap, Revit, Rhinoceros	—	Structure (building – bath)
Varna Monument (Aksoy & Kaya, 2025)	Kırklareli	Photogrammetry LiDAR (iPhone 15 Pro)	Agisoft Metashape, Scaniverse (mobile LiDAR capture), SketchUp	—	Structure (monument)

aims to develop a holistic approach based on the HBIM methodology in the reconstruction process of digital heritage. During the data collection phase, the structure was documented using LiDAR scanning and UAV (drone) photogrammetry techniques; these data were processed in Agisoft Metashape and Autodesk ReCap Pro software to produce dense point cloud and mesh models. The acquired point cloud data were organized in the Rhinoceros environment and then transferred to the Autodesk Revit environment (Yörük, 2025). In the HBIM modelling process, algorithmic modelling tools were used to parametrically create complex geometries. This model was later transferred to Autodesk Navisworks software; here, the integration of different data sources, the timeline of construction phases (4D simulation), and clash detection of intervention scenarios were carried out. The use of Navisworks enabled the HBIM

model to be integrated with multidisciplinary data management and was used as a primary source in reconstruction planning (Yörük, 2025).

Association the management process of restoration and conservation projects of historic buildings in Turkey with HBIM technology: A case study

This example was evaluated using the data obtained from the study by Garip (2023). Using the Ferdane Hanım Mansion in İzmit as a case study, a comparative analysis was conducted between traditional documentation methods and HBIM-based digital documentation methods in terms of process, accuracy, and efficiency. In the initial documentation phase, the structure was recorded through hand measurements, manual drawings, photographs, and on-site observations, and the data were transferred into a digital environment using conventional CAD software. This process took approximately three months (Garip, 2023). In the subsequent HBIM-based phase, the structure was documented through laser scanning, and the resulting point cloud data were processed in Autodesk ReCap and transferred to Autodesk Revit. Enscape was used to enhance three-dimensional visualization and stakeholder communication. In contrast to the traditional method, the HBIM-based process was completed in only 17 days (Garip, 2023). This case demonstrates that HBIM can significantly reduce documentation time while improving data continuity, visualization, and coordination among project stakeholders.

Research on the use of historic building information modelling (HBIM) technique on immovable cultural heritage at Afyonkarahisar Grand Mosque for documentation purposes

This example was evaluated based on the data obtained from the study conducted by Tunay (2022). The research examines the applicability of the Heritage Building Information Modelling (HBIM) method for documentation purposes in immovable cultural heritage assets, using the Afyonkarahisar Ulu Mosque as a case study. In the study, the data collection process was carried out in two stages: first, manual measurements of architectural elements such as windows and doors were conducted using sketches and steel measuring tapes; second, point cloud data were obtained through laser scanning (Tunay, 2022). These data were processed and integrated using various software tools, including Trimble RealWorks, Autodesk ReCap, FARO Scene, Autodesk Revit, and Graphisoft Archicad (Tunay, 2022).

A mesh model was generated from the point cloud data and then transferred into the Revit and Archicad environments to create a digital information model. Revit was used for processing point cloud data and parametric modelling, while Archicad supported the modelling of complex geometries specific to historic structures. Through the HBIM process, geometric data, material textures, photographs, and 2D drawings were integrated into a single digital platform and supported by a virtual tour interface. Compared to traditional documentation methods, this approach minimized data loss, increased measurement accuracy, and facilitated the digital archiving of heritage documentation (Tunay, 2022).

Case studies of restoration processes with the hbim and example of the Church of Isparta Aya Yorgi

This example was analysed based on the data obtained from the study conducted by Günay (2025). The case of the Aya Yorgi Church in Isparta represents an applied research study examining the integration of HBIM technology into the restoration processes of historic structures. During the data collection phase, the structure was scanned using a FARO Focus3D laser scanner, and this process took approximately three days (Günay, 2025). The resulting point cloud data were organized in Autodesk ReCap and subsequently transferred to the Autodesk Revit environment. In the following modelling phase,

which lasted five days, the geometry of the structure, material properties, and detailed architectural components were created within Revit. For visualization and the testing of restoration scenarios, the Enscape plugin was utilized, allowing spatial perception, lighting conditions, and material effects to be analysed in a realistic manner (Günay, 2025).

Historical building information modelling (HBIM) application: the case of Pertev Mehmet Paşa Mosque

This example was evaluated using the data obtained from the study by Çelik (2023). Through the case of the Pertev Mehmet Paşa Mosque in Kocaeli, the study evaluates the applicability of HBIM as a documentation and digital modelling tool for cultural heritage structures. During the data collection process, the structure was documented with the FARO Focus3D laser scanner and this process took approximately three hours (Çelik, 2023). The obtained point cloud data were processed and cleaned in Autodesk ReCap software and then transferred to the Autodesk Revit environment. During the modelling process, the details of the structure were created at the LOD 300 level; however, some complex cultural heritage elements (for example decorations and original stone details) could not be fully modelled in the Revit environment. For this reason, representative models were created for these parts, and since the addition of detailed geometries required manual modelling, the expected level of time saving could not be achieved in the process (Çelik, 2023). Despite this, the HBIM method enabled the documentation of the overall geometry and spatial relationships of the structure with high accuracy and provided an important contribution in terms of digital archiving.

Archaeological heritage information management: HBIM Erythrae (Ildır)

This example was evaluated using the data obtained from the study by Sarıcaoğlu (2021). The study examines how the HBIM approach can be used for archaeological data management and documentation in the Erythrai (Ildır) archaeological heritage site. The aim of the research is to develop an integrated HBIM-based information management methodology that transfers the multilayered data of archaeological remains into the digital environment. During the data collection process, the site was measured using terrestrial laser scanning (TLS) and photogrammetry techniques; for the Heroon structure, high-resolution data were obtained through a total of 24 scanning positions over 175 minutes (Sarıcaoğlu, 2021). Since the obtained point clouds came from different resolutions and sources, they were aligned using the Iterative Closest Point (ICP) algorithm and a single geometric dataset was created. In the data processing and modelling stage, orthophotos were produced from the point cloud, 3D surface models and detailed analyses were carried out; information related to the structure and stone elements was integrated through programs that provide a NURBS infrastructure in the BIM environment (Sarıcaoğlu, 2021). This method increased data accuracy by providing high-precision and reliable representation in structures with complex and irregular geometries such as archaeological heritage sites, while also enabling the development of conservation decisions.

The heritage building information modelling (Heritage BIM) and refunctioning through 3-D documentation of the Mehmet Aga House

This example was evaluated using the data obtained from the study by Odabaşı (2022). It aims to digitally document the historic Mehmet Ağa Mansion located in Ankara and to develop a Heritage Building Information Model (HBIM), with the objective of providing a scientific basis for the future restoration and adaptive reuse processes of the building. During the data collection phase, the mansion was scanned in a total of 44 sessions using a FARO Focus M70 terrestrial laser scanner, and the fieldwork was completed in 13.5 hours; the point cloud data

obtained from the scans were combined in FARO Scene software (Odabaşı, 2022). The acquired point clouds were then cleaned and georeferenced in Autodesk ReCap software and converted into ReCap Project (.rcp) format before being transferred to the Autodesk Revit environment. The HBIM model was developed in Revit, and modelling was carried out by referencing the point cloud data to accurately represent complex and deteriorated architectural elements; this process provided higher geometric accuracy and digital integrity compared to traditional documentation methods (Odabaşı, 2022). Special elements such as windows, doors, and the roof dome were modeled separately and later integrated into the model. The three-dimensional model of the building was used as an effective tool to support future restoration decisions (Odabaşı, 2022).

BIM utilization in restoration projects: Mahmud Pasha Hammam

This example was evaluated using the data obtained from the study by Çügen (2022). The study examines the applicability of the BIM approach within a professional restoration implementation project carried out on the 15th-century Mahmud Pasha Bath in Golubac, Serbia. During the data collection process, the structure was scanned using a Faro Focus LS 120 terrestrial laser scanner, and 8.42 GB of point cloud data were obtained from 83 scan positions. In addition to laser scanning, photographs, videos, and material samples were collected to support the documentation process (Çügen, 2022). The point cloud data were merged in Faro Scene, converted through Autodesk ReCap, and transferred to AutoCAD and Revit environments. Auxiliary tools such as WebShare2Go, Rhinoceros, and SAP2000 were also used for data sharing, flexible modelling, and structural analysis (Çügen, 2022).

The applied workflow increased measurement accuracy and reduced data loss by enabling point cloud data to be processed directly within CAD/BIM environments. It also supported the creation of a shared dataset for multi-stakeholder coordination through the WebShare2Go platform. However, the ruinous condition of the bath, organic wall surfaces, and non-standard geometries limited the full representation of the structure in Revit. For this reason, Rhinoceros was used as a complementary tool for modelling irregular forms (Çügen, 2022). Overall, the case demonstrates the contribution of BIM to information sharing, data integrity, technical documentation, cost estimation, and multidisciplinary coordination in restoration projects.

Archiving historical heritage with photogrammetry and lidar: the case of Kırklareli Varna (Karahıdır) monument

This example was evaluated using the data obtained from the study by Aksoy and Kaya (2025). The study, conducted on the Varna (Karahıdır) Monument in Kırklareli, compares mobile LiDAR technology and photogrammetry in terms of accuracy, time, and cost. Three documentation methods were used: photogrammetry, mobile LiDAR, and manual measurement. During the data collection process, 142 photographs were taken for photogrammetric modelling, an iPhone 15 Pro was used for mobile LiDAR scanning, and traditional measuring tools were used for reference measurements. Agisoft Metashape was used to process photogrammetric data, Scaniverse was used for mobile LiDAR data acquisition and processing, and SketchUp was used for architectural analysis. These tools were considered suitable for the geometric and visual modelling of the monument as a medium-scale single structure.

In terms of time and cost efficiency, mobile LiDAR was found to be the most efficient method. The scanning and model generation process with Scaniverse took 2 minutes and 15 seconds, whereas the processing of photogrammetric

data, including depth maps and point cloud generation, took approximately 21 minutes (Aksoy & Kaya, 2025). In terms of accuracy, LiDAR measurements were found to be consistent with manual reference measurements and provided the level of precision required for restoration-oriented documentation. Photogrammetry, on the other hand, produced stronger results in visual texture and surface representation, although some geometric deviations were observed. Therefore, the study indicates that mobile LiDAR is more effective for speed and geometric accuracy, while photogrammetry is more suitable for visual presentation and texture mapping. The case demonstrates that the integrated use of mobile LiDAR and photogrammetry can provide a low-cost and time-efficient documentation strategy, particularly where access to high-cost terrestrial laser scanners is limited.

HBIM Applications Abroad

At the international level, Heritage Building Information Modelling (HBIM) applications were initially developed within the scope of academic studies and pilot projects; however, they have now evolved into advanced practices that strengthen interdisciplinary collaboration in the fields of architecture, archaeology, and cultural heritage conservation. In recent years, the increasing awareness of digital transformation has enabled HBIM to be used as an effective tool in the documentation, analysis, conservation, and restoration processes of historic structures. Within this context, numerous projects have been carried out abroad, and various applications at different scales—particularly in Italy as well as in other countries—have been examined, as summarized in Table 2.

A HBIM pipeline for the conservation of large-scale architectural heritage: The city walls of Pisa

This example was evaluated using the data obtained from the study by Giuliani et al. (2024). It focuses on the development of a large-scale HBIM process for the conservation of the Pisa city walls located in the Tuscany region of Italy. The aim of the research is to establish a fast, accurate, and integrated digital method for documenting, analysing, and preserving historical architectural heritage that extends across large areas. During the data collection process, photogrammetry and topographic measurement techniques were used together. The images were processed in Agisoft Metashape software, location data were supported by total station measurements, and the accuracy of the models was ensured (Giuliani et al., 2024). The obtained point clouds were transferred to Rhinoceros software; here, the HBIM model was created in the Graphisoft Archicad environment using the Grasshopper plugin and Archicad. The project was applied to a 405-meter section of the approximately 7 km long city walls and aimed to document both geometric deformations and material deterioration (Giuliani et al., 2024). This method developed a reliable digital data infrastructure that can be used in making planned conservation decisions by providing a low-cost, highly accurate, and time-efficient documentation process in large-scale cultural heritage sites.

HBIM for archaeological sites: From SfM based survey to algorithmic modelling

This example was evaluated using the data obtained from the study by Bagnolo et al. (2019). In the study, the applicability of the HBIM method in the digitalization process of archaeological structures was examined within the scope of research conducted on the architectural elements of the columned front façade (pronaos) of the Temple of Antas located on the island of Sardinia in Italy. The main aim of the research is to evaluate the effectiveness of algorithmic modelling methods in transferring historical structural elements with complex geometries into the BIM environment. During the data collection process, the Structure from Motion (SfM)–based photogrammetry method was used (Bagnolo et al.,

Table 2. HBIM Projects International Context (created by the author)

Case Study		Comparison Criteria			
Study Name	**Location**	**Data Collection Method**	**Suitability of the Software Used**	**Plugins Used and Their Contribution to the Project**	**Project Scale**
Pisa City Walls (Giuliani et al., 2024)	Italy	Photogrammetry (iPhone 11)	Agisoft Metashape, Rhinoceros, Archicad, Grasshopper	Grasshopper: Facilitates the modelling of amorphous structures	Structure (historic city walls)
Colonnade of the Temple of Antas (Bagnolo et al., 2019)	Italy	Photogrammetry, laser scanning	Autodesk Revit, Dynamo	Dynamo: Generates complex forms through algorithmic modelling when parametric modelling is insufficient	Structural element (temple column)
Church of San Nicolo (Banfi, 2022)	Italy	Photogrammetry, laser scanning	AutoCAD, Rhinoceros, Revit	—	Structure (archaeological remains)
A Heritage Building in Massawa (Sewasew & Tesfamariam, 2023)	Eritrea	Photographic data, orthophoto	Photoshop, Revit	—	Structure (civil building)
The Duomo of Molfetta (Nieto-Julian et al., 2024)	Italy	Terrestrial laser scanning, photogrammetry	Archicad, Cyclone	Archicad Teamwork: Used for team collaboration; BIMvision: Used to examine interactions among stakeholders in the HBIM model	Structure (religious building – basilica)
The Castle of Maredolce (Allegra et al., 2024)	Italy	Laser scanning method (3 days)	Cyclone, 3D Reshaper (point cloud software), Revit, Rhinoceros	—	Structure (castle)
Parma Cathedral (Bruno & Roncella, 2018)	Italy	Topographic survey, laser scanning, photogrammetry	Archicad, Cyclone, Rhinoceros, Revit	Revit plugin: Developed to attach orthophotos to the model, produce 2D thematic maps, and automatically transfer this data to the 3D model	Structure (religious building – basilica)
Centre Block, Parliament Hill (Banfi et al., 2018)	Canada	Photogrammetry, laser scanning	ContextCapture, Pointools, Scene, ReCap, Rhinoceros, Revit	Automatic verification system (AVS): A tool that automatically measures and validates deviations between the point cloud and the 3D model	Structure (administrative building)
The Church of St. Francesco at Rocca Calascio (Trizio & Savini, 2020)	Italy	Photogrammetry	Agisoft, Meshlab, Revit, SketchUp	—	Structure (archaeological remains)
Two Arab-Norman Churches (Aricò et al., 2023)	Italy	Laser scanning, photogrammetry, topographic survey	Autodesk ReCap, Agisoft Metashape, CloudCompare, Revit	—	Structure (religious building – church)

2019). The obtained images were processed in Agisoft Photoscan software to generate dense point cloud data, enabling the digital representation of surface geometries with millimetric accuracy. These produced data were transferred to Autodesk Revit software, and the algorithmic modelling process was carried out through the Dynamo plugin (Bagnolo et al., 2019). The mentioned software minimized data loss, preserved model integrity, and provided a high level of accuracy in parametric modelling. The study was conducted at the scale of a single archaeological structure and particularly focused on the parametric and algorithmic modelling processes of columns, capitals, and base elements.

HBIM, 3D drawing and virtual reality for archaeological sites and ancient ruins

This example was evaluated using the data obtained from the study by Banfi (2020). The research was conducted on the San Nicolò Church and the surrounding archaeological remains located in the village of Bajardo in the Liguria region of Italy. During the data collection process, photogrammetry and terrestrial laser scanning (TLS) methods were used together, and the obtained high-resolution data were processed through NURBS-based modelling using Rhinoceros, AutoCAD, and Autodesk Revit software (Banfi, 2020). This software chain (Rhinoceros–Revit) minimized data loss and ensured high geometric accuracy and multi-layered information transfer (Banfi, 2020). Although the project was carried out at the scale of a single structure, it covered the ruined church of a historic village and the surrounding archaeological remains, thereby presenting an exemplary model for the digital documentation and virtual reconstruction of cultural heritage.

Historic building information modelling using image: example of port city Massawa, Eritrea

This example was evaluated using the data obtained from the study by Sewasew and Tesfamariam (2023). The study aims to develop a low-cost, image-based HBIM method for documenting and preserving cultural heritage structures with limited accessibility in the port city of Massawa in Eritrea. The main objective of the research is to create parametric HBIM models of historic structures using only photographic data in cases where access to modern surveying equipment (such as LiDAR or TLS) is not available, thereby addressing the documentation gap in developing countries (Sewasew and Tesfamariam, 2023). During the data collection process, available visual sources such as individual façade photographs, Google Earth images, maps, and archival documents were used; these images were corrected in Adobe Photoshop to produce scaled façade drawings. Subsequently, the model was created using Autodesk Revit 2022 software. GIS-based location data and historical architectural drawings were integrated into the process. The accuracy of the method was tested by comparing the results with architectural drawings dated 1927, and it was determined that measurement differences were generally minimal, indicating a high level of geometric accuracy (Sewasew and Tesfamariam, 2023). The study was implemented at the scale of a single structure and façade. By enabling the production of HBIM models solely from photographic data without the use of modern scanning technologies, the method offers a sustainable, low-cost, and accuracy-based solution for the digital documentation and conservation of heritage sites with limited accessibility.

An efficient process for the management of the deterioration and conservation of architectural heritage: The HBIM project of the Duomo of Molfetta (Italy)

This example was evaluated using the data obtained from the study by Nieto-Julián et al. (2024). The research was conducted on the Duomo di Molfetta Cathedral located in the Puglia region of Italy and aims to develop an effective HBIM methodology to optimize the management of deterioration and conservation processes of the historic structure. In the study, the data collection process was carried out through the combined application of terrestrial laser scanning (TLS) and photogrammetric techniques. The obtained point clouds were processed using Cyclone software. The photogrammetric data produced with Agisoft Metashape were integrated into the Archicad 27 environment. The resulting datasets were semantically separated according to structural elements (such as columns, vaults, and walls) and subsequently exported in IFC format (Nieto-Julián et al., 2024). Accuracy assessments were conducted through comparisons between the point cloud and the parametric model (Nieto-Julián et al., 2024). The high accuracy of the method enabled the millimetric detection

of column deformations and wall cracks. Collaboration was supported through Archicad Teamwork, allowing real-time and up-to-date data sharing among the project stakeholders involved in the study (Nieto-Julián et al., 2024).

Scan-to-BIM for The Management of Heritage Buildings: The Case Study of The Castle of Maredolce (Palermo, Italy)

This example was evaluated using the data obtained from the study by Allegra et al. (2020). The research was conducted on the Maredolce (Favara) Castle from the Arab–Norman period located in Palermo, Italy, and examines the applicability of the Scan-to-BIM process for the documentation, conservation, and management of historic structures. The main aim of the study is to develop a usable digital data infrastructure for conservation and restoration planning by generating a highly accurate HBIM model of a historic structure with complex geometries from laser scanning data. The data collection process was carried out using Leica RTC360 and FARO Focus 3D laser scanners (Allegra et al., 2020). The data were registered and aligned in Leica Cyclone software and organized through filtering in the 3D Reshaper program. The point cloud data were transferred to the Autodesk Revit environment, where both parametric and non-parametric modelling strategies were applied; custom models were created for elements with complex geometries, and unique forms were modeled in Rhinoceros software and integrated into Revit. An HBIM model at the LOD 2–3 level was produced (Allegra et al., 2020). The resulting model integrated the geometric, material, and functional data of the structure within a single digital platform, enabling the digital management of restoration, maintenance, and conservation processes.

A restoration oriented HBIM system for cultural heritage documentation: The case study of Parma Cathedral

This example was evaluated using the data obtained from the study by Bruno and Roncella (2018). The research was conducted on the Parma Cathedral located in Parma, Italy, and aims to develop a restoration-oriented HBIM system specifically designed for the documentation, maintenance, and restoration of historic structures. The main objective of the study is to create a flexible, accurate, and user-friendly digital system capable of managing complex geometries, irregular forms, and multi-layered data specific to historic buildings. During the data collection process, topographic surveying, laser scanning, and photogrammetry were used together to document both the interior and exterior spaces of the structure in three dimensions. The photogrammetric processing was carried out in Agisoft Photoscan software, while the laser scanning data were registered and aligned in Leica Cyclone software to ensure accuracy (Bruno and Roncella, 2018). Rhinoceros software was used to accurately model elements with complex geometries. The HBIM model was created in the Autodesk Revit environment. In addition, a custom-developed plugin for Revit enabled the automatic transfer of 2D deterioration and material maps derived from orthophotos into the 3D model, thereby integrating the thematic mapping process for restoration planning directly into the BIM environment (Bruno and Roncella, 2018).

Building information modelling for cultural heritage: The management of generative process for complex historical buildings

This example was evaluated using the data obtained from the study by Banfi et al. (2018). The research addresses the "advanced modelling techniques" process developed for the digitalization of complex historic structures, through the case of Confederation Hall located within the Centre Block of the Parliament Building in Ottawa, Canada. The main objective of the study is to create accurate, parametric digital models compatible with structural analysis

for historic structures with highly complex geometries. During the data collection process, point cloud data obtained from three different 3D laser scanners were integrated with photogrammetry, archival drawings, historical photographs, and CAD data (Banfi et al., 2018). The acquired scanning data were cleaned and optimized using Context Capture, Pointools, Scene, and Autodesk ReCap software. In the modelling stage, free-form surfaces were created in Rhinoceros software and subsequently transferred to Autodesk Revit and Graphisoft Archicad environments. The project was conducted at the scale of a single interior architectural space (Confederation Hall), and a highly detailed model at the LOD 300–500 level was produced (Banfi et al., 2018).

Archaeology of buildings and hbim methodology: İntegrated tools for documentation and knowledge management of architectural heritage

This example was analysed using the data obtained from the study by Trizio and Savini (2020). The research was conducted on the San Francesco Church located in Rocca Calascio in the L'Aquila region of Italy and proposes a multidisciplinary method for integrating data obtained through archaeological analyses into the HBIM environment. During the data collection phase, the photogrammetry method was used; the images were processed in Agisoft Photoscan software and subsequently merged in Meshlab software (Trizio and Savini, 2020). In this way, the resulting photorealistic 3D model was validated through geometric and color verification, and high-resolution 2D orthophotos and plan sections were also produced.

During the modelling process, the Stratigraphic Wall Units identified on the wall surfaces were classified chronologically through archaeological analyses, and this information was integrated into the HBIM model. Parametric modelling was tested through two different methods: the first directly within Autodesk Revit software, and the second by transferring models created using SketchUp (2019 version) into Revit. This method increased model accuracy by integrating photogrammetry and archaeological databases; metric verification was carried out in the Revit environment, resulting in a geometrically consistent and information-rich HBIM model. The project was implemented at the scale of a single structure, and a highly accurate digital twin was developed in which archaeological, structural, and historical data were integrated within the same digital model.

A scan-to-BIM approach for the management of two Arab-Norman churches in Palermo (Italy)

This example was evaluated using the data obtained from the study by Aricò et al. (2023). The study focuses on the Scan-to-BIM–based HBIM application carried out on the St. John the Baptist of the Lepers and St. John the Evangelist of the Hermits churches in Palermo. The aim of the research is to examine the effectiveness of digital technologies in the documentation, analysis, and conservation management processes of these two medieval structures from the Arab–Norman period. During the data collection phase, terrestrial laser scanning (TLS), drone photogrammetry (UAV), and topographic surveying methods were used for the first structure; however, due to legal restrictions, only TLS scanning was applied for the second structure (Aricò et al., 2023). The scanning operations took several days. The data were processed using Autodesk ReCap, Agisoft Metashape, and CloudCompare software, and subsequently an HBIM model was created in the Autodesk Revit environment (Aricò et al., 2023). During the modelling stage, programs allowing more flexible work were required for complex geometries. All special elements were additionally modeled and added to the Revit library, which required additional time. The deviations from

the reference points obtained through laser scanning were evaluated, and the accuracy of the method was confirmed (Aricò et al., 2023).

DISCUSSION

In the field of HBIM (Heritage Building Information Modelling), the international literature has developed rapidly in recent years; particularly in Europe-based projects, comprehensive case studies have been published focusing on process management, data integrity, cost optimization, and software integration. In contrast, the number of academic studies on HBIM in Türkiye remains limited, and the existing body of knowledge is largely based on academic theses. At the implementation level, the number of comprehensive and multidisciplinary HBIM projects is quite low. This situation leads to limitations in both methodological comparisons and the production of comprehensive data related to process and cost management. Large-scale studies published abroad, supported by advanced hardware–software infrastructures, archival resources, and expert teams, provide more concrete outputs regarding how HBIM processes can be optimized.

Discussion of Time Management

In HBIM projects conducted abroad, processes are generally completed in a shorter time due to the effective use of advanced hardware and software infrastructures, the availability of institutional digital archives, and the presence of interdisciplinary teams specialized in HBIM. The integrated use of software such as Autodesk Revit, Graphisoft Archicad, and Rhinoceros facilitates smoother transitions between data collection, modelling, and analysis stages, thereby improving workflow efficiency.

In contrast, HBIM applications in Türkiye generally require longer processing times. This is largely due to the lack of institutional digital archives, limited numbers of specialists experienced in HBIM workflows, and restrictions in access to licensed software. Nevertheless, case studies such as the Ferdane Hanım Mansion demonstrate that HBIM-based documentation can significantly reduce project durations compared to traditional methods.

Discussion of Cost Management

When evaluated in terms of cost management, it is observed that in HBIM projects conducted abroad, although high investments are made in hardware and licensed software at the initial stage, the total project cost can be optimized in the long term. The main reason for this is the significant reduction in labor and time costs as HBIM processes are completed in a shorter period. In particular, the use of data collection methods with high initial investment costs, such as laser scanning (LiDAR/TLS), together with or as an alternative to photogrammetry techniques, enables the establishment of a balance between cost and accuracy. In international case studies, it has been observed that integrating high-resolution laser scanning data with lower-cost photogrammetric data within the same model shortens the fieldwork duration while maintaining acceptable levels of accuracy.

In Türkiye, HBIM applications tend to rely on more limited technical equipment and alternative software in order to reduce initial investment costs. While this approach lowers short-term expenses, it may increase manual modelling efforts and extend project duration. Despite these limitations, HBIM still offers significant long-term economic benefits through improved data management, digital archiving, and more efficient maintenance and restoration processes.

Discussion of the Data Collection Process

In HBIM projects conducted abroad, the data collection process is generally based on a hybrid approach combining laser scanning (LiDAR, TLS) and photogrammetry. High-precision devices such as Leica RTC360, FARO Focus 3D, and Nikon NPL 350 are frequently used, as their ability to produce dense point clouds allows the current condition of structures to be represented with millimetric accuracy. While laser scanning improves geometric reliability, particularly for structures with complex geometries and deformations, photogrammetry provides complementary data for surface textures and visual details. The combined use of these two methods ensures that both geometric accuracy and visual information are comprehensively transferred to the model, thereby increasing the accuracy and reliability of the HBIM model (Aksoy and Kaya, 2025).

In Türkiye, although similar data collection methods are used, drone-based photogrammetry is more frequently preferred to reduce hardware costs. While this approach decreases fieldwork time and initial investment costs, it may result in lower geometric accuracy compared to laser scanning. In cases involving irregular surfaces, interior spaces, or detailed architectural elements, reliance solely on photogrammetry can limit model accuracy. Therefore, the balance between cost efficiency and model accuracy remains a key factor influencing the quality of HBIM processes in Türkiye.

Discussion of the Software Used in the Data Processing and Modelling Process

In the data processing and integration stage, combining laser scanning and photogrammetry data from different sources within a single coordinate system is essential. In the examined HBIM projects, software such as Agisoft Metashape, Autodesk ReCap Pro, and Cyclone Register 360 are widely used for aligning heterogeneous datasets, removing noise, and improving coordinate accuracy. Cyclone Register 360 is particularly effective in the automatic alignment of laser scanning data, while Agisoft Metashape is commonly used for generating photogrammetric data and transferring texture information into models. Autodesk ReCap Pro functions as an intermediary platform for transferring point cloud data into BIM environments.

During the modelling stage, Autodesk Revit, Graphisoft Archicad, and Rhinoceros emerge as key tools within HBIM workflows. While Revit and Archicad support information-based modelling through parametric BIM infrastructures, Rhinoceros is frequently used for modelling complex and irregular cultural heritage geometries. Visual programming plugins such as Dynamo and Grasshopper further support algorithmic modelling, enabling the efficient creation of repetitive or complex elements. Additionally, Autodesk Navisworks facilitates model integration, 4D time simulations, clash detection, and schedule control, supporting overall project management processes.

HBIM technology contributes significantly to reducing project duration and improving cost management. The integration of photogrammetry and laser scanning data within the same model can considerably shorten fieldwork time. Although HBIM applications are gradually increasing in Türkiye, limitations such as restricted digital archives, software licensing costs, and a lack of specialized experts still hinder the full realization of these advantages (Garip, 2023). Nevertheless, existing studies demonstrate that HBIM provides substantial time savings and cost reductions compared to traditional documentation methods.

CONCLUSION

This study aimed to evaluate the Heritage Building Information Modelling (HBIM) approach in the documentation and sustainable management of cultural heritage structures not only as a documentation tool but also as a decision-support system from the perspective of time and cost management. For this purpose, the research was conducted within the framework of a qualitative research method; in line with the research questions defined by the author, a total of 20 HBIM projects selected from Türkiye (10 cases) and international context (10 cases) were comparatively analysed. As a result of the comparative analyses, the following key findings regarding the effects of HBIM processes on project management were identified:

- HBIM as a Tool for Process Efficiency and Management: In the examined cases, HBIM was found to improve project efficiency by integrating geometric data, material information, documentation records, and visual outputs within a single digital environment. This integration reduces data fragmentation, supports more coordinated decision-making, and strengthens communication among project stakeholders. Therefore, HBIM functions not only as a modelling system but also as a management platform that can guide documentation, restoration, maintenance, and conservation processes.
- Time and Cost Efficiency through Integrated Workflows: The findings indicate that the contribution of HBIM to time and cost management depends on the relationship between data acquisition methods, software environments, and modelling strategies. Laser scanning and LiDAR-based methods generally support faster and more accurate data acquisition, while photogrammetry provides advantages in visual documentation and texture mapping. Hybrid workflows combining these methods offer a more balanced approach in terms of accuracy, time, and cost.
- Software Integration and Process Coordination: The use of BIM-based software and complementary tools such as Revit, Archicad, Rhinoceros, Dynamo, Grasshopper, Navisworks, and visualization platforms contributes to more coordinated and information-rich project processes. These tools support different stages of HBIM workflows, including point cloud processing, parametric modelling, algorithmic form generation, visualization, clash detection, and process planning. In this respect, software interoperability is a critical factor in transforming HBIM from a documentation method into a project management tool.
- Comparative Findings between Türkiye and International Contexts: The comparison between Türkiye and international examples reveals a clear difference in terms of project management maturity. International HBIM applications generally demonstrate more integrated workflows supported by advanced hardware, specialized teams, institutional archives, and software interoperability. In contrast, HBIM applications in Türkiye are still developing mainly through academic studies, pilot projects, and individual research initiatives. Although limitations related to software access, digital archives, technical expertise, and project budgets affect the continuity of HBIM-based workflows, the Turkish cases also show that HBIM can provide significant advantages over traditional documentation methods, particularly in reducing data loss, shortening documentation time, and improving stakeholder coordination.

As a result, the comparative evaluation shows that HBIM applications international context generally demonstrate a more advanced structure in terms of process management, cost efficiency, software integration, and data accuracy, whereas HBIM practices in Türkiye are still in a developmental stage. However, the cases

examined in Türkiye indicate that growing academic interest, university-based research, and the increasing use of digital tools provide an important basis for the future integration of HBIM into cultural heritage management. In this context, HBIM should not be addressed only as a technical documentation method, but as a multidimensional project management approach that supports decision-making, conservation planning, maintenance strategies, and long-term data management.

This study contributes to the literature by examining HBIM from a project management perspective and by comparing its time and cost implications in Türkiye and international contexts. The findings indicate that the systematic use of HBIM can support more efficient documentation, reduce data loss, improve stakeholder coordination, and strengthen decision-making in cultural heritage projects. Future studies should focus on developing national HBIM standards, expanding practice-based training models, creating institutional digital archives, and testing HBIM workflows through field-based applications.

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Research Article

Reconstructing Literary Space Using Artificial Intelligence-Enhanced Architectural Representation Methods: Georges Perec And The Plassaert Apartment

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Abstract

Positioned at the intersection of literature and architecture, this study explores how abstract spaces constructed in literary texts can be reconstructed using architectural representation tools and artificial intelligence technologies. The focus of the research is the Plassaert apartment in Georges Perec's Life: A User's Manual, which details the space through everyday objects and lists, and the users of this space across different periods. The object-human relationships, hoarding tendencies, and the psychological weight of the space described in the text have been transformed into architectural representations through artificial intelligence (ChatGPT, Gemini, Copilot). The study's methodology is based on a spatial accumulation model constructed around the parameters of Actor, Space, and Time. The 5-Level Prompt Model has transformed these literary data into a visual language, producing the spatial counterpart of each actor in their own time. Within the scope of the findings, the layering created by the material concerns, psychological and social states of space users through objects has been concretised through spatial indicators. The narrative structure in Perec's literature (chess and jigsaw puzzle metaphors) has been represented through conceptual collages. In the final stage, plan and section planes were superimposed simultaneously, developing a representational model where the temporal traces left by different actors in the same physical space can be read in a multi-layered manner. In conclusion, this research demonstrates that literature offers a multi-layered research field for architectural analysis and representation; it also reveals that AI-supported tools can play a supportive role in visualizing this layered structure.

Keywords: Architectural Representation, Artificial Intelligence, Georges Perec, Layering, Life: A User's Manual.

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INTRODUCTION

The discipline of architecture approaches space not merely as a structural phenomenon bounded by physical limits, but also as a multilayered field of experience where social narratives, individual memory, and everyday practices intersect (Bachelard, 2014). In this context, literature constitutes a fundamental field that expands the boundaries of spatial thought and provides rich data for architectural analysis. In the process of transforming a textual narrative into an architectural data source, Georges Perec's Life: A User's Manual (La Vie mode d'emploi) serves as a significant example in its inventory of space through small details, lists of objects, and daily rhythms.

The translation of spatial descriptions in literary texts from the mental realm to a visual and architectural representational plane shares similarities with the translation process. Producing an architectural counterpart for the described objects, actions, and atmosphere requires subjecting them to spatial analysis (Jakobson, 1959). However, this representational process often carries the risk of remaining abstract. Reading an author's poetics through a single section (the Plassaert apartment) and transforming this reading into an architectural representation necessitates methodological clarity in the transition from text to image. Conventional architectural representation tools—ranging from manual drafting and physical collages to contemporary digital environments such as CAD and Building Information Modeling (BIM)—fundamentally rely on metric precision, Euclidean geometry, and static temporal conditions. While these traditional media excel at codifying physical boundaries, material assemblies, and functional zoning, they inherently struggle to register the intangible dimensions of spatiality: the psychological weight of everyday rituals, subjective domestic atmospheres, and the temporal sedimentation of human presence. In contrast, literary narratives construct space through fragmented inventories, emotional states, and sequential occupancies that resist static orthographic projection. The unique contribution of this study to the discipline of architecture lies in bridging this epistemological gap. By introducing an AI-augmented Actor–Space–Time methodology, the research expands the traditional boundaries of architectural representation beyond metric documentation into a form of narrative spatial archaeology.' This approach allows architects not only to visualize the non-metric and affective nuances of narrative environments but also to decode unbuilt, erased, or multi-temporal spaces that conventional representation methodologies cannot systematically transcribe.

To establish this operational clarity, this study proposes a generative framework grounded in the triad of Actor, Space, and Time, centering on the Plassaert apartment in Perec's Life: A User's Manual. By systematically translating domestic accumulation, personal inventories, and sequential occupancies into spatial prompts, the research demonstrates how Generative AI tools (ChatGPT, Gemini, Copilot) can reconstruct literary narratives into layered architectural representations. The primary objective is not merely illustrative rendering, but the critical exploration of how the act of reading can be transformed into spatial analysis through the simultaneous overlay of architectural plans, cross-sections, and narrative collages.

To address this objective, the research is guided by three fundamental research questions:

RQ1: How can non-metric, qualitative spatial descriptions, character psychology, and everyday object inventories in literary texts be systematically translated into architectural representational media (plans, sections, and collages)?

RQ2: What is the operational and theoretical role of Generative AI within this translation process? Specifically, does it function merely as an automated visualization engine, an interpretive mediator, or an emergent method of architectural representation?
RQ3: To what extent can the three-parameter framework (Actor–Space–Time) provide an adaptable and generalizable methodology for decoding narrative space across broader literary contexts beyond Perec's specific narrative structure?

THEORETICAL FRAMEWORK

Architectural Representation and the Digital Transformation of Representational Tools

Representation, in its broadest sense, is the act of substituting for something, or re-presenting it through another medium, language, or form (Mitchell, 1990). In philosophical and artistic contexts, representation is a mental, critical, and interpretive reconstruction of the perceived or imagined world (Goodman, 1978). In this context, within the discipline of architecture, representation goes far beyond merely showing or communicating what is to be built; it is recognized as the very act of thinking and designing itself (Allen, 2000). Expressing a space through tools such as plans, sections, collages, or perspectives actually makes the atmosphere, objects, and traces of the user's experience within that space legible. Thus, architectural representation is a field of production where abstract ideas and textual constructs are rewritten in a spatial language.

Throughout history, architectural representation tools have undergone a profound evolution, shifting from conventional manual drawings to digital modeling (CAD/BIM) and algorithmic design. Traditional and early-stage digital tools typically rely on precise metric data, geometric coordinates, and predefined rules generated by the designer. However, the integration of AI-based algorithms into architectural representation is bringing about an epistemological shift in how representation tools are used and understood (Leach, 2022).
As an architectural representation tool, artificial intelligence (ChatGPT, Gemini, Copilot) possesses the ability to convert textual data (prompts) and semantic relationships into visual data. This makes artificial intelligence an ideal tool for translating spatial descriptions—particularly in fields like literature, which rely on words and are open to interpretation—into architectural representations. AI-supported representation tools transform the clusters of objects and lived experiences within the space described by the author into a new architectural representation.

In recent years, the integration of Generative AI into architectural representation has shifted computational discourse from rule-based parametric modeling toward semantic, multimodal translation (Leach, 2022; Picon, 2021). Current scholarship highlights that diffusion models and Large Language Models (LLMs) fundamentally challenge conventional orthographic drawing by treating representation as an open-ended, synthetic dialogue (As, 2024; Carta, 2023). However, utilizing AI within scholarly architectural research presents distinct epistemological and technical limitations. First, generative text-to-image engines lack intrinsic geometric coordinates and Euclidean dimensional rigor; they interpret spatial depth purely through probabilistic visual patterns rather than orthographic metric logic (Del Campo, 2022; Leach, 2022). Second, these models are prone to visual hallucinations, semantic drift, and inconsistent spatial orientation across sequential prompt iterations (Grosz, 2023). Consequently, Generative AI cannot operate as an autonomous design authority. To achieve scientific validity in architectural inquiry, generative tools require a structured, rule-based methodological scaffold—such as controlled multi-tiered prompting

and systematic parameter pairing—that constrains computational stochasticity and aligns generative outputs with rigorous architectural intent.

Georges Perec

In Georges Perec's literary universe, space is not a fixed plane. It is defined as a constant source of doubt and a territory to be conquered. In his work *Espèces d'espaces* (*Spaces*), the author argues that space can only exist through marking and definition. Perec's practice of constructing space focuses not on major historical events but on the microscopic details of daily life, which he terms "infra-ordinary." A table, a drawer, a room, or a forgotten object are, for Perec, the foundational elements of the narrative (Perec, 1974/2017). This approach reveals that Perec's spaces function as spaces constructed through objects and lists.

Hoarding, Layering, and Spatial Memory

In spatial theory, the relationship between human psychology and physical space is fundamentally mediated by material culture and domestic objects. While Bachelard (2014) approaches domestic space through the poetic lens of intimate memory and oneiric verticality, contemporary spatial theory and narrative architecture argue that lived space is an active social and material construct rather than a passive container (Psarra, 2009; Rendell, 2006). Literary narratives provide unique analytical access to this dynamic; as Ricoeur (1984) and Spurr (2012) articulate, narrative architectures materialize character consciousness through spatial syntax and mundane domestic possessions. In Georges Perec's structuralist poetics, the domestic interior is not an empty volumetric void to be furnished, but an archaeological deposit formed by everyday life, routine practices, and physical accumulations (Sheringham, 2006). Objects in Life: A User's Manual operate as material indices of time, financial anxieties, and psychological distress. However, traditional architectural analysis frequently separates the physical fabric of the room from its subjective material sediments. Bridging narrative theory with spatial analysis therefore requires an interpretive medium capable of treating literary inventories as spatialized behavioural data.

In Perec's narrative, the construction of characters is achieved indirectly through the material environment and objects, rather than through traditional psychological analyses. As seen in the example of the Plassaert apartment, the hoarding tendencies exhibited by the users experiencing the space, the constant layering of objects, and the resulting stratification within the space are the primary elements shaping the spatial experience. The space functions almost like a warehouse where past lives and daily practices accumulate. This layered use of space is deepened by the presence of different characters:
The Plassaert family's identity as collectors and their material concerns are reflected in the space through specific object choices, such as keeping flowers that do not wilt or are already dead. The cramped nature of the space dictates the characters' rhythms of life through physical constraints, such as the bed not being able to open unless the table is closed (Perec, 1978/2023).

Grégoire Simpson: The character's mental state is not explicitly described in the text using the word "depression." Instead, it is conveyed indirectly through spatial indicators, such as his lying in bed with his knees drawn up to his chest and his using an old slipper as an ashtray (Perec, 1978/2023).

Troyan: The fact that Troyan, the previous tenant who was a used bookseller, has filled the attic with piles of books and objects reaching up to the ceiling represents the layers of memory within the space. (Perec, 1978/2023).

In conclusion, in Perec's poetics, objects assume a more dominant role than characters, becoming the carriers of memory and identity. This two-way relationship between space and the user expresses a dynamic process that results in the space coming to resemble its user and the way the user lives their life over time. To operationalize these theoretical notions within the architectural analysis, the core terminology is structured across behavioural, physical, and temporal registers (Table 1). While 'hoarding' denotes the behavioural mechanism of accumulation and 'layering' describes its spatial stratification, 'sediment' is conceptualized not merely as a passive physical deposit, but as the tangible material residue left by temporal traces within the domestic envelope over successive occupancies.

Concept	Operational Definition / Usage in Study
Hoarding	Behavioural accumulation pattern
Layering	Spatial-stratigraphic condition
Sediment	Material residue of temporal occupation
Accumulation	Overarching spatial-temporal process

Table 1. Key Concepts Used in the Study

METHOD

The methodology operates as a structured operational pipeline translating non-metric literary narratives into architectural representations across three sequential phases (Figure 1):

Phase 1: Conceptual Categorization. The literary text (Life: A User's Manual) is systematically parsed to identify textual descriptions of domestic accumulation and temporal residue, establishing the core conceptual framework.

Phase 2: Parametric Translation. These conceptual notions are operationalized into architectural design criteria by pairing textual behaviours with analytical axes: actor (hoarding/inhabitation tendencies), space (physical spatial boundaries and layout), and time (chronological succession and temporal depth).

Phase 3: Computational Synthesis. The parametric inputs are processed through an iterative 5-Level Prompt Model utilizing artificial intelligence engines (ChatGPT, Gemini, Copilot), progressing from character-specific visual atmospheres to multidimensional superimposed plan-section drawings (Figure 1).

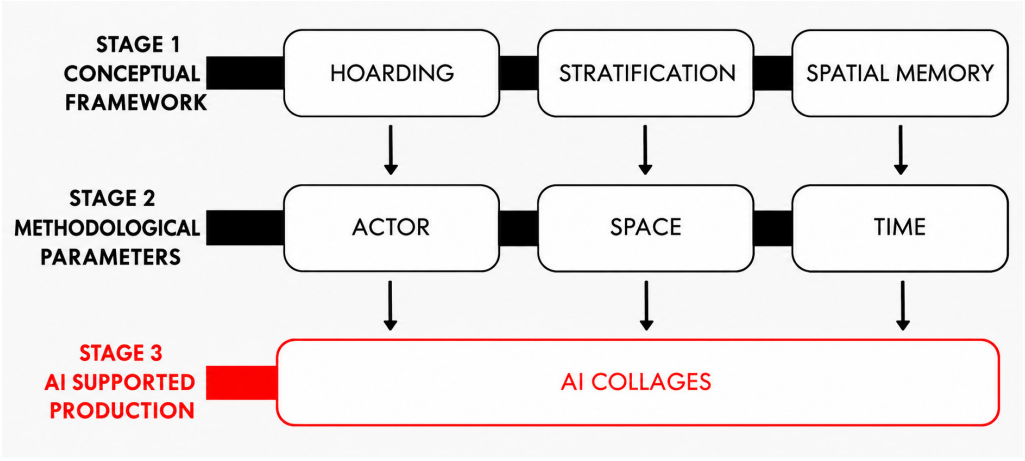


Figure 1. Flowchart of the Three-Stage Methodology for the Reconstruction of Literary Space (Image created by the authors).

Spatial Accumulation Through Actor, Space, and Time Parameters
Data Selection and Textual Coding Process

To establish methodological transparency, the textual dataset was extracted from Georges Perec's Life: A User's Manual based on two criteria: (1) explicit inventories of material possessions and (2) clear descriptions of spatialized daily routines. Centering on the top-floor Plassaert apartment, the study selected three narrative sequences representing distinct temporal layers and occupant profiles: the Plassaert family, Troyan, and Grégoire Simpson (Chapters 53, 54, and 72).

The qualitative literary data were codified into architectural parameters through a structured coding matrix (Table 2). Descriptive textual excerpts were parsed into 'Behavioural/Material Indicators,' which were subsequently translated into 'Spatial Parameters' (spatial density, surface condition, vertical stratification) to feed directly into the prompt architecture.

Table 2. Textual Coding and Parameter Extraction Matrix

Actor & Chapter	Textual Excerpt / Narrative Cue	Thematic Code	Architectural & Spatial Parameter
Grégoire Simpson (Ch. 53)	"...lying in bed, knees drawn up to his chest, smoking... using an old slipper as an ashtray."	Spatial inertia, physical isolation, negligence	Low horizontal density, messy central core, neglected surfaces, dark atmospheric tone
Troyan (Ch. 54)	"...piles of books and papers reaching up to the ceiling, leaving narrow corridors to walk."	Professional hoarding, archival storage	High vertical density, labyrinthine circulation, linear floor-to-ceiling boundaries
Plassaert Family (Ch. 72)	"...the table could not be unfolded unless the bed was closed... vases with wilted and artificial flowers."	Economic constraint, utility-driven accumulation	Functional spatial conflict, overlapping furniture layouts, artificial material textures
Temporal Synthesis (All)	The shared physical shell of the apartment occupied across successive time frames.	Multi-temporal sedimentation	Layered section planes, isometric superposition, simultaneous temporal depth

The methodological framework of this study is structured around three fundamental parameters: Actor, Space, and Time (Table 3). The concepts of accumulation and layering prominent in Georges Perec's narrative were not interpreted merely as the gathering of objects. Instead, they were approached as a holistic reading of the traces left by different actors within their own temporal frames on the same spatial plane (the Plassaert apartment)(Table 3).
In the initial phase of the production process, the multi-layered structure of the literary text was broken down into its components. The three main actors experiencing the Plassaert apartment (the Plassaert family, Troyan, and Grégoire Simpson) were analyzed independently of one another. Each actor's use of space, inventory of objects, psychological state, and material concerns were represented as separate collages of the apartment's current state at that moment, with the assistance of artificial intelligence (Figures 2, 3, 4, 5).

Within this analytical framework, the domestic accumulations within the apartment are interpreted not as clinical diagnoses or empirical facts, but as plausible behavioural inferences derived from textual indicators (Table 4). For the Plassaert family, spatial congestion can be interpreted as an accumulation reflex shaped by economic constraints and material anxieties, manifested through utilitarian objects and non-perishable decorations. For Grégoire Simpson, spatial negligence and immobility are read as narrative indicators of psychological inertia and depressive isolation. For Troyan, the ceiling-high stacks of books and papers are framed as spatial traces of professional identity and archival accumulation. These inferences do not claim definitive psychological truths; rather, they serve as operative conceptual parameters to structure the architectural prompts.

Table 3. Methodology Table

Basic Parameter	Analysis	Artificial Intelligence Function and Narrative	Architectural Representation
Actor (Plassaert Family, Troyan, G. Simpson)	Independent examination of each actor's hoarding tendencies and psychological states	Transformation of textual descriptions into character-specific visual prompts.	Independent spatial collages reflecting only the actors' own experiences (their own states).
Space (Plassaert Apartment)	Identifying that different actors actually share the same physical space.	Compiling the resulting inventories of objects and actor silhouettes onto a common spatial substrate.	Experiments in conceptual layering where objects overlap within the physical boundaries of the space.
Time (Temporal Depth)	Reinterpreting accumulation as the buildup of actors within the space over their own times.	Overlaying plan and section planes based on the logic of simultaneity and parallelism (Interstellar reference).	A multidimensional architectural representation with temporal depth that dissolves all actors and their lived experiences into a single plane.

Table 4. Actor Motivations and Temporal Layering

Parameter	Actor	Hoarding Motivation (Authors' Inference)	Spatial Correspondence
ACTOR	Plassaert Family	Financial Concerns	Artificial/dead flowers, utilitarian objects.
ACTOR	Grégoire Simpson	Depression and Inactivity	Dirty ashtrays, a messy bed, spatial neglect.
ACTOR	Troyan	Professional Identity (Bookseller)	Piles of books and paper reaching the ceiling.
TIME	Synthesis	Temporal Accumulation	The overlapping of all motivations within the same physical boundary.

Transition from Text to Prompt

In the first stage of the AI-driven collage production process, the original descriptions of the setting from the book were directly imported into the ChatGPT tool to convert these texts into visual generation prompts. These prompts were then transferred to the Gemini and Copilot tools to create the first AI-generated collages of the setting.

Visual Backgrounds, Object Inventory, and Collage Composition

In subsequent stages of collage production, the goal was to go beyond the textual narrative and add a subjective interpretation to the setting. In this regard, a suitable visual background capable of expressing the space's layered nature was identified, and a detailed inventory of objects was compiled using the Gemini tool based on the descriptions in the texts.

While constructing the collage, the structural characteristics of the literary work were symbolically integrated into the visual composition. Given his role as the work's creator, Georges Perec is represented in the collage as an integral element, albeit in an abstract form. Additionally, drawing on the author's structuring of the narrative through the knight's move in chess, the knight figure has been used as a key symbol in the collage. The resulting inventory of objects, along with this abstracted image of the author and the chess knight, was processed onto a predefined background via the Gemini tool, thereby uniting the text's physical and conceptual dimensions within a single visual plane (Figure 7).

Five-Level Prompt Model

Based on the necessity for a good prompt to be clear, goal-oriented, and context-sensitive, a systematic method was followed in transferring textual data to artificial intelligence. This process—in which what is desired is clearly stated, the format is defined, the tone and style are selected, a specific role is assigned to the AI, and constraints are added—was structured using an analytical layering model. During the production process, by adding a new function to

Table 5. 5-Level Prompt Generation Method

Level	Function	Representation Result
1	General Topic	Superficial Scene
2	Focus	Spatial Readability
3	Context	Atmosphere
4	Analysis	Temporal Layering
5	Perspective	Disciplinary Interpretation

the request at each level, the quality of the visual representation was guided toward a disciplinary architectural interpretation (Table 5).

Computational Workflow and Prompt Architecture

The generation pipeline divided analytical tasks across specific AI tools according to their computational strengths:

ChatGPT (GPT-4): Used for qualitative semantic parsing, extracting narrative keywords, and converting textual quotes into structured descriptive prompt frameworks.

Gemini: Utilized for cross-referencing object inventories, structuring spatial hierarchies, and generating contextual architectural collages with authorial metaphors (chess knight, puzzle).

Copilot (DALL-E 3 engine): Deployed for high-fidelity spatial synthesis, rendering architectural section-perspectives, planar overlays, and atmospheric textures.

To demonstrate reproducibility, Table 6 illustrates the operational application of the 5-Level Prompt Model using Grégoire Simpson's room as a representative log.

Table 6. Operational 5-Level Prompt Log (Representative Case: Grégoire Simpson)

Level	Operational Target	Input Prompt Structure (Syntax)	Representation Target
Level 1	Base Context	"A small attic room in a Parisian apartment, 1970s, domestic interior."	Broad volumetric layout
Level 2	Spatial Enclosure	"...cramped garret space, sloped ceiling with dormer window, peeling wallpaper, unmade iron bed."	Orthographic/spatial legibility
Level 3	Atmospheric Tone	"...dim light entering from the window, heavy and dusty atmosphere, melancholic tone, worn parquet floor."	Materiality and sensory tone
Level 4	Narrative Sediment	"...scattered cigarette butts, an old slipper used as an ashtray next to the bed, unwashed coffee cups on the floor."	Behavioural indices and object inventory
Level 5	Disciplinary Synthesis	"Architectural collage style, section-perspective view, combining ink drawing textures with conceptual planar overlay, muted color palette."	Final disciplinary architectural representation

Using this model, the process was transformed into multilayered visuals that ensured spatial legibility step by step, captured the atmosphere of the era, reflected the psychological states of characters such as Grégoire Simpson through objects, and ultimately produced an interpretation at the intersection of architecture and literature.

Visual Selection and Quality Assessment Criteria

Because generative diffusion engines produce stochastic outputs across identical prompt runs, a systematic four-tier selection protocol was implemented to curate the final representations from iterative image batches (approximately 15–20 iterations per scene):

Narrative-Spatial Fidelity: The visual must explicitly register the primary object inventories and character behaviours cited in Perec's text without introducing unrelated modern artefacts.

Architectural Legibility: The generated scene must maintain recognizable architectural boundaries (demarcating walls, openings, sloped roof geometry, and floor planes) rather than dissolving into purely abstract digital art.
Atmospheric and Material Consistency: Textures, light distribution, and object densities must accurately reflect the specific psychological and temporal condition attributed to the occupant (e.g., depressive stagnation vs. archival book piles).

Disciplinary Representation Value: For planar and sectional overlays, priority was given to outputs that preserved orthographic and isometric conventions, enabling simultaneous reading of horizontal circulation and vertical volume.

PROCESS AND FINDINGS

Object-Human Relationship

During the text analysis process, the most prominent finding regarding object-human relationships within the Plassaert apartment is that users experiencing the space exhibit hoarding tendencies. The accumulation of objects, resulting in a layered and stacked condition within the space, is visualized as the primary factor shaping the spatial experience. The visualizations depict the users' hoarding tendencies and the layered arrangement of objects within the apartments (Figures 2-5)





Figure 2. Grégoire Simpson's Apartment (Image generated by artificial intelligence)
Figure 3. The Plassaert Family's Small Apartment (Image generated by artificial intelligence)





Figure 4. The Troyan Apartment (Image generated by artificial intelligence)
Figure 5. The Plassaert Family's Other Apartment (Image generated by artificial intelligence)

The Construction and Visualization of Psychological Space

The psychological weight in Perec's text reaches its peak when we examine the condition of the character Grégoire Simpson. Perec does not use clinical terms such as "depression" to describe Grégoire Simpson's condition. Instead, the narrative indirectly conveys psychological withdrawal through spatial behaviours and physical postures. Simpson's posture—lying in bed fully clothed with his knees drawn up to his chest and using a discarded slipper as an ashtray—is interpreted in this study as a textual manifestation of depressive spatial inertia (Perec, 1978/2023). Although alternative literary interpretations exist, this specific interpretation has been functionalized as a spatial parameter to guide the creation of an atmosphere of spatial neglect and domestic confinement (Figure 6). Perec describes the character of Grégoire Simpson and his state of mind as follows:

One day, at two in the morning, his right-hand neighbor, a young student named Troyan, noticed that the light in the student's room was still on as he was returning home; he knocked on the door but received no answer; he knocked again, waited a moment, pushed open the door—which wasn't quite closed—and found Grégoire Simpson in bed; with his knees drawn up to his chest, fully clothed, his eyes open, smoking a cigarette clamped between his middle and ring fingers; he was using an old slipper as an ashtray. When Troyan entered, he didn't look at him; the bookseller asked, "Are you sick? What happened? Do you want some water? Do you need anything?" He didn't answer, and only when Troyan lightly touched his shoulder to make sure he was dead did he suddenly turn toward the wall and mutter, "Leave me alone" (Perec, 1978/2023, p. 284).

The Abstract Representation of the Object Inventory and Narrative Structure

The spatial analysis of the Plassaert apartment has been deepened through the visualization of the concepts of "play" and "constraint" that guide Perec's narrative. Two distinct conceptual collages have been created to represent the



Figure 6. The transformation of Grégoire Simpson's actions into spatial indicators (Image generated by artificial intelligence).

complexity of the object inventory described in the text and the author's mental construct.

In the first visualization (Figure 7), a spatial composition is presented that deepens and fragments toward the center in the shape of a circular vortex. At the center of this composition is the "knight's figure from chess," representing the constraint Perec used to navigate between apartment rooms while writing *Life: A User's Manual*. The author's position observing the space from above, combined with everyday objects scattered around (ashtray, typewriter, clock, record player), forms a map of the literary text's inventory of objects. Differences in color and layers are used to distinguish each user of the apartments.

In the second visualization (Figure 8), a triangular geometry (roof form) is centered, referencing the space's location on the top floor. Filling the interior of the triangle with a jigsaw puzzle pattern symbolizes the main character's jigsaw puzzles in the work. The jigsaw puzzle, which contains the space's past and current occupants (Grégoire Simpson, Troyan, and the Plassaert family), conveys this in a dramatic manner. The "Please Close Your Eyes" sign, anchored by the text in the room, and the piles of objects surrounding it are blended with a black-and-white, engraving-like texture, freezing the space's layers within a single frame (Figure 8).

Multidimensional Representation: The Simultaneous Overlap of Plan and Section

The visual findings obtained following the separation process revealed that all these distinct lives and actors actually share the same physical boundaries (the Plassaert apartment) and converge through the parameter of time. This observation necessitated the use of the time factor as a unifying plane during the artificial intelligence phase. In this context, the visual productions have been transformed into a multidimensional temporal depth narrative through artificial intelligence. By simultaneously merging all actors and their lived experiences across different time periods into a single plane, the literary space's multi-layered and profound spatial accumulation spanning from the past to the present has been represented (Figure 7).

In the final phase of the study, the aim was to translate the simultaneous, holistic, and multi-layered structure present in Perec's literature onto an architectural plane. In this regard, drawing on previously generated plan and section visuals, the goal was to achieve an overlay resembling the multi-dimensional parallelism logic seen in the film *Interstellar*. Plan and section, traditional tools of architectural representation, typically present space from a single-dimensional



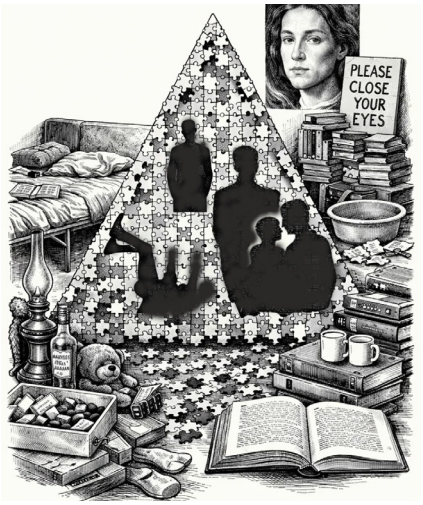
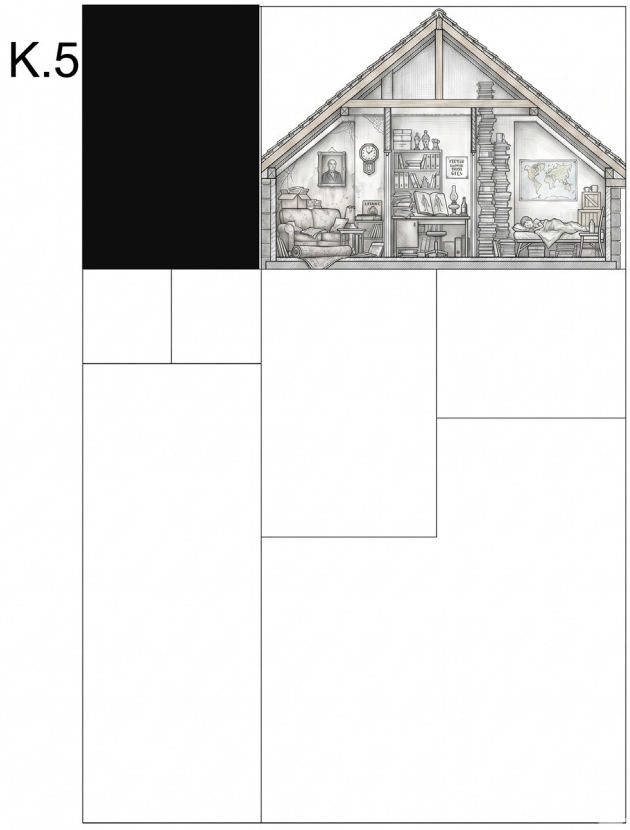


Figure 7. The inventory of objects in the Plassaert apartment and an abstract representation of Perec's chess move narrative (Image generated by artificial intelligence)
Figure 8. Visualization of the characters' spatial silhouettes through the puzzle metaphor of the attic form (Image generated by artificial intelligence)

perspective. However, the Plassaert apartment is a space where the past and present lives of various actors—such as Grégoire Simpson, Troyan, and the Plassaert family—converge within the same physical boundaries, and where time is layered and spatialized (Figures 9, 10).

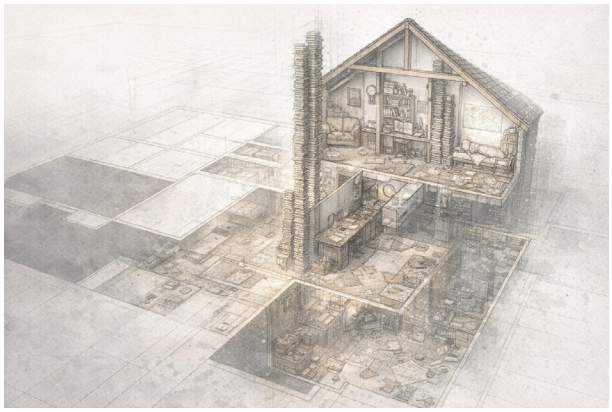


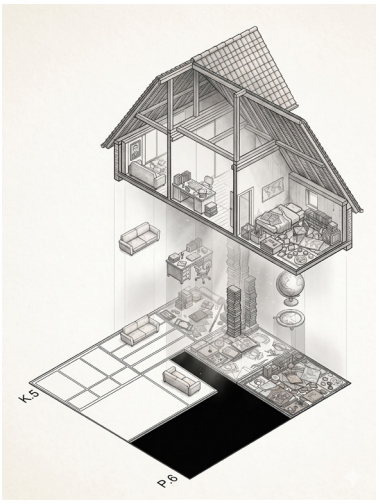
Figures 9. Plan and section planes generated with AI assistance (Images created by AI).



Figures 10. Plan and section planes generated with AI assistance (Images created by AI)

To visualize this complex structure, floor plans and sections previously generated by artificial intelligence were synthesized with the tesseract structure from the film *Interstellar*. The primary motivation for choosing this reference is the conceptual framework provided by the scene in the film where parallel universes are depicted, allowing time to be experienced simultaneously as a layered space (tesseract). Just as the film visualizes the past, present, and future as overlapping in an infinite and sequential series of chambers, departing from a linear timeline, temporal layering in this study is also treated as a series of interconnected spatial units. In line with this approach—seen as the most powerful way to express experiences from different time periods simultaneously—new prompts entered into AI tools have synchronously overlaid the horizontal life map of the plan with the vertical physical depth of the cross-section. Through this model, spatial data belonging to the actors have been materialized in a multidimensional manner on a single plane (Figures 11, 12)





Figures 11-12. Multidimensional overlay of plans and sections generated by AI assistance, inspired by the film *Interstellar* (Images generated by AI).

DISCUSSION AND CONCLUSION

Throughout this study, the question of what architectural representation represents has been reopened for discussion in the process of reinterpreting Georges Perec's narrative structure through artificial intelligence. Analyses conducted on the Plassaert apartment have shown that space is not so much a static structure defined by physical boundaries, but rather a layered memory field where users' psychological states, economic concerns, daily habits, and temporal traces accumulate. In this context, the phenomenon of hoarding examined in the study has been interpreted not merely as the proliferation of objects, but as the sedimentation of time within space. In particular, the repeated filling of the same physical boundary by different actors across different periods has revealed that space is, in fact, a structure that is constantly being rewritten.

This situation demonstrates that, in Perec's understanding of space, the relationship between the user and the space is not one-sided. The user is, in fact, a producer who transforms the character of the space by imprinting their own life, mood, and daily rhythm onto the physical environment. Objects and traces of use that accumulate over time make the lived quality of the space visible. Thus, the Plassaert apartment transforms into an archive that preserves the traces of past users, layers them upon one another, and is reshaped with each new user.

In this context, the visuals produced in the study do not represent a completed state of the space but rather make visible a process of accumulation that is

Figures 12. Multidimensional

constantly evolving and never reaches a final form. In particular, the multi-layered representational experiments achieved by superimposing plan and section views break the traditional structure of architectural drawing, enabling the simultaneous reading of different times within the same space. Thus, the space is treated as a temporal density carrying the residues of past lives. Rather than representing a completed state, the act of interpreting a constantly evolving and never-finalized process of accumulation is directly related to the structural framework of Georges Perec's * Life: A User's Manual *. Perec's deliberate decision to end his novel at the ninety-ninth chapter, without reaching the hundredth, demonstrates his conscious rejection of the narrative as a complete, closed, and flawless whole. This missing final piece, much like the puzzle metaphor in the work, implies that the whole can never be fully attained. For this reason, the representations produced do not aim to depict the space in its completed state. On the contrary, by making visible the missing pieces, the overlapping experiences, and the unresolved temporal residues, they translate Perec's deliberate practice of omission into the architectural representational plane.

To understand the broader implications of this research for architectural practice and theory, the proposed AI-supported workflow must be critically situated against traditional architectural representation paradigms. Conventional orthographic media (plans, sections, axonometrics) and contemporary parametric BIM models prioritize spatial clarity through singular snapshots in time and precise geometrical coordinates. However, they typically exclude lived experience, emotional deterioration, and the historical buildup of inhabitation within identical physical perimeters. Manual architectural collages, while more capable of handling evocative atmospheres, remain static and heavily dependent on isolated subjective manual assemblages.

The unique methodological contribution demonstrated in this study operates on three distinct disciplinary levels:

Temporal Simultaneity over Static Metrics: Unlike CAD/BIM setups that isolate revisions into distinct, non-overlapping design options or phases, the AI-driven tesseract-inspired overlay enables the simultaneous visual coexistence of asynchronous occupants (Grégoire Simpson, Troyan, and the Plassaert family) within a single spatial register.

Translation of Non-Metric Qualitative Data: The workflow establishes a systematic bridge between literary description and architectural spatialization, translating qualitative conditions—such as depressive spatial inertia, domestic hoarding, and professional accumulation—into spatial textures and densities without forcing them into premature dimensional grids.

Generative Analytical Tool for Conceptual Design: Beyond retrospective literary analysis, this framework provides architects and architectural students with an operative design medium. It enables designers to treat narrative, memory, and occupant psychology as generative parameters during the formative phases of architectural design, expanding representation from a tool of post-facto presentation into an active instrument of spatial inquiry.

Regarding the operational role of artificial intelligence in this translation process (addressing RQ2), the findings demonstrate that Generative AI is neither a passive image generator nor an autonomous spatial author. Instead, it functions as an **interpretive cognitive mediator and an emergent representational medium**. Operating within human-defined architectural constraints, the AI engines

(ChatGPT, Gemini, Copilot) process qualitative, non-metric textual descriptions through the 5-Level Prompt Model, translating latent psychological and spatial relationships into tangible visual syntax. The agency remains firmly anchored in the researcher's analytical framework, while AI acts as a computational bridge between textual narrative and spatial representation.

urthermore, regarding the broader applicability of the methodology (addressing RQ3), while this study specifically investigates the Plassaert apartment in Georges Perec's Life: A User's Manual, the conceptual logic of the Actor–Space–Time framework is theoretically adaptable rather than strictly case-bound. Perec's text provides an ideal laboratory due to its exhaustive inventories and structured spatial constraints. However, because the study's empirical testing is limited to this single setting, its universal validity remains to be demonstrated across diverse literary works. Nonetheless, the core operational pipeline—deconstructing narrative cues into behavioural motivations (Actor), architectural perimeters (Space), and temporal accumulation (Time)—offers a transferable methodological scaffold. This structure provides a potential analytical framework for future inquiries investigating narrative environments where material culture, everyday routines, and spatial memory are foregrounded.

Limitations and Future Research Trajectories

While the proposed methodology demonstrates a systematic framework for narrative spatialization, several intrinsic limitations must be acknowledged. First, because the computational outputs were curated and evaluated based on qualitative architectural criteria established by the authors, the findings inherently carry an interpretive dimension. Future research could enhance evaluative objectivity by integrating multi-expert panels (e.g., Delphi methods with architects and literary critics) or empirical user-perception studies to assess the atmospheric fidelity of AI-generated spatial representations. Second, the empirical scope of this study was intentionally restricted to a single architectural volume—the Plassaert apartment in Georges Perec's Life: A User's Manual. While this single-case focus enabled an exhaustive, micro-spatial analysis of domestic accumulation, testing the cross-applicability and robustness of the Actor–Space–Time model requires expanding the workflow to broader narrative settings, urban-scale literature, and varied literary genres with differing structural constraints.

Consequently, this study reinterprets the Plassaert apartment from Georges Perec's * Life: A User's Manual * through a methodology developed based on the parameters of Actor, Space, and Time, thereby demonstrating how literary space can be materialized using architectural representation tools. Thanks to the method employed in the study, the traces left by different users in the same physical space, object relationships, and temporal stratifications were evaluated together; a multi-layered representational language was developed through plans, sections, collages, and AI-assisted visualizations. In this context, the research demonstrates that the relationship between literature and architecture can constitute a methodological and representation-focused field of production.

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Authors Contribution:

All authors individually 1) participated in the design process, collecting data and analysing the data examined, 2) participated in writing the draft and critically evaluating the content, 3) approved the final version of the article and took all responsibility for this manuscript.
Beyza Özdemir: %50 - Prof. Dr. Arzu Özen Yavuz: %50

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Research Article

Adaptive Reuse of Industrial Heritage: The case of Kütüphane Troleybüs

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Abstract

The loss of function of industrial heritage buildings makes their preservation and adaptive reuse an important issue. This study examines the adaptive reuse of the Trolleybus Power Center in Beyazıt, Istanbul, as a Kütüphane Troleybüs and evaluates the effects of the interventions on the original building. A qualitative research method was adopted. The study included a literature review on the conservation and adaptive reuse of industrial heritage, an examination of plans, photographs, and archival data, and on-site observations of the building. The collected data were evaluated in terms of the preservation of the building's original architectural, structural, and technical features; the level of intervention; the distinguishability of new and existing elements; compatibility with the existing building; and spatial organization. The findings show that the building's high-volume interior space, structural system organization, and traces of its technical infrastructure have been largely preserved. Study areas, mezzanine arrangements, and other functional units introduced for library use were designed in relation to the building's existing spatial characteristics. The visible preservation of technical equipment and infrastructure elements supports the legibility of the building's industrial character within its new use. The spatial organization of the library function also supports preserving the original spatial character while accommodating different functional requirements. Overall, the study demonstrates that adaptive reuse can preserve the original features of industrial heritage while integrating existing buildings with contemporary use requirements.

Keywords: Adaptive Reuse, Industrial Heritage, Library Buildings, Trolleybus Power Center.

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INTRODUCTION

Since the beginning of human existence, people have continuously engaged in production in order to sustain their vital activities. In the early periods, production was carried out through the use of tools and relied primarily on human labor. Over time, however, this method was replaced by mechanization, and production processes came to be largely conducted through machines. This transformation facilitated the widespread adoption of machine-based production and contributed to the emergence of the concept of industry in its present scope (Özdemir, 2015; Batur & Batur, 1970). The history of industrial and manufacturing activities extends far earlier than the Industrial Revolution. Indeed, one of the earliest known examples of industrial production was the shipyard established in Venice in 1104, which operated through a system resembling serial production (Köksal, 2005). Over time, factors such as increasing needs, resource shortages, technological developments, and competition accelerated production activities. This accumulated development paved the way for the emergence of the Industrial Revolution, which began in the 18th century and continued until the early 20th century (Özdemir, 2015; Hançerlioğlu, 1981). This transformation was not limited to Europe but also influenced different geographical regions. In the Ottoman Empire, industrialization movements intensified particularly during the 19th century, and this process largely developed in Istanbul and its surrounding areas. During this period, the increase in foreign capital, labor force, and the number of factories contributed to the transformation of the city into an industrial center. Nevertheless, the roots of Istanbul's industrial production tradition date back to earlier periods. The Tershane-i Âmire and Tophane-i Âmire, whose foundations were established in the 15th and 16th centuries, were among the city's prominent industrial structures (Köksal & Ahunbay, 2010).

In the later stages of the Industrial Revolution, not only production facilities but also industrial structures serving urban transportation and infrastructure systems gained importance. Particularly after World War II, the expansion of electric transportation systems, the construction of new roads, and the development of existing transportation networks led to a significant increase in demand for urban transportation. In the early 1950s, this growing demand was met through minibuses, shared taxis, public buses, and trams. However, following the removal of tram systems toward the end of the 1950s, the primary burden of urban transportation was transferred to bus and trolleybus systems (Arısal, 2025). During this process, the power centers supplying the energy required by these systems became important components of the urban fabric. Constructed to provide electricity for trolleybus systems, these structures reflected the industrial approach of their period not only through their technical functions but also through their architectural characteristics.

The production structures that emerged with the Industrial Revolution gradually lost their functions as a result of technological developments and changing production conditions, and some subsequently became abandoned. Today, structures such as factories, workshops, warehouses, and transportation infrastructure are considered part of industrial heritage (TICCIH, 2003). The abandonment of these structures as a result of technological developments and changing production conditions has increased the importance of their conservation and adaptive reuse (Ayvaz & Halaç, 2023).

At this point, the conservation of cultural heritage becomes particularly important. Cultural heritage is defined as the entirety of assets that provide information about the past experiences of a society and have survived to the present through continuity (İstanbul Valiliği, İstanbul İl Afet ve Acil Durum

Müdürlüğü, & İstanbul Proje Koordinasyon Birimi, 2014). In this respect, it establishes a connection between the past and the present, contributes to shaping the future, and provides direction for conservation practices (Kurtar & Somuncu, 2013). Historic buildings, as tangible components of this heritage, carry architectural, cultural, religious, and economic traces of the periods in which they were constructed and thus provide significant information about the past. Therefore, the conservation of such structures and their transmission to future generations are of great importance (Tunçer & Can, 2022). However, as these buildings may not always meet the needs arising from contemporary socio-economic conditions, they can gradually become underutilized or abandoned (Göçer, 2003). This situation has made the adaptation of functionally obsolete buildings to contemporary use an important conservation approach (Büyükarslan & Güney, 2013).

Adaptive reuse refers to adapting functionally obsolete buildings to contemporary usage requirements and is defined by Ernest Burden as "the modification of a building to meet new needs" (Burden, 2004, p. 215). This approach aims to bring buildings back into use while preserving their identity and prioritizing the sustainability of their original fabric. In this context, adaptive reuse is not merely a process of physical intervention but also a conservation approach that aims to ensure cultural continuity.

The institutionalization of the conservation approach at the international level was significantly shaped by the 1964 Venice Charter and organizations such as UNESCO, ICOMOS, and ICOM. Within this process, which also includes Türkiye, the concept of conservation has evolved from an approach focused solely on preserving the physical integrity of buildings to one that also encompasses adaptive reuse strategies aimed at ensuring their sustainable survival (Özdemir, 2015). Article 5 of the Venice Charter states that the use of monuments for a socially useful purpose facilitates their conservation; however, it emphasizes that such new use should not alter the layout or decoration of the building and that interventions should be limited (ICOMOS, 1964). Within this framework, interventions are expected to be compatible with the original character while remaining distinguishable from the existing building (Büyükarslan & Güney, 2013). Similarly, Tunalı and Güneş (2024) state that new interventions should establish an integrated relationship with the existing building without allowing the original character of the structure to be overshadowed. At the same time, the adoption of the new function by users and its ability to be sustained over time are also important. In this context, the acceptance of the resulting new identity by society plays a decisive role in ensuring the continuity of the building's use (Tunçer & Can, 2022).

In the adaptive reuse of industrial buildings, it is important to preserve their original architectural character and spatial qualities while configuring the arrangements required by the new function in a manner compatible with the existing building (Yalçın, 2024). This process enables industrial sites to be reintegrated into urban life while also supporting sustainability (Kariptaş, 2010). In addition, the effective utilization of large-scale spaces within these buildings provides economic and spatial contributions to the urban environment (Tunçer & Can, 2022). Accordingly, the conservation and adaptive reuse of industrial heritage constitute an important design approach in terms of ensuring cultural continuity, preserving collective urban memory, and making effective use of the existing building stock (Çeltekligil & Arabacıoğlu, 2025).

Within this framework, one of the fundamental issues in the adaptive reuse of industrial heritage buildings is establishing a relationship between the

spatial arrangements required by the new use and the original architectural character of the building. In particular, evaluating the preservation of the original architectural, structural, and spatial characteristics together with the interventions carried out as part of the new use is important for determining the quality of the transformation.

International studies examining how the relationship between original building characteristics and new-use requirements is established across different buildings and functions provide opportunities for comparison. Within this scope, three examples directly related to the subject and evaluative framework of this study were selected for comparison. The LocHal Library in Tilburg provides a basis for comparison in terms of adapting an industrial building to a library function and relating the requirements of the new use to the existing space. Tate Modern in London offers a comparative example regarding the transformation of a large-scale energy infrastructure structure into a cultural facility and the adaptation of its existing spatial character to a new function. The Large Machine Factory in China, on the other hand, provides a basis for comparison in terms of authenticity, minimal intervention, and the recognizability of new interventions in the adaptive reuse of industrial heritage (Sedes & Mumcuoğlu, 2023; Shin, 2025; Xiong et al., 2023). These three examples enable the preservation of original characteristics, the level of intervention, and the relationship between the new use and the existing building to be discussed through different applications.

Within the scope of this study, the adaptive reuse of the former Trolleybus Power Center in Beyazıt, Istanbul, as Kütüphane Troleybüs is examined. The aim of the study is to examine the interventions carried out during the transformation process and to evaluate their effects on the original building. Accordingly, the historical development of the building, its original architectural characteristics, industrial heritage values, and the modifications made in accordance with its library function are examined. In addition, the relationship between the preserved original elements and the interventions carried out as part of the new use is evaluated in terms of the conservation approach, functional requirements, and spatial organization. The study aims to contribute to the existing body of knowledge on the adaptive reuse of transportation-related industrial heritage buildings and to provide insights for similar transformation projects.

In line with this aim, the study seeks to answer the following research questions:

RQ1. How have the original architectural, structural, and technical characteristics of Kütüphane Troleybüs been preserved during the adaptive reuse process?
RQ2. How can the adaptive reuse of Kütüphane Troleybüs be evaluated in terms of minimal intervention, the distinguishability of new and old elements, and compatibility with the existing building?
RQ3. How can the new function of Kütüphane Troleybüs be evaluated in terms of spatial organization, preservation of the original spatial character, and the ability to accommodate different use scenarios?

METHOD

Research Design and Data Collection

This study was designed as a qualitative case study examining the adaptive reuse process of the Trolleybus Power Center in Beyazıt, Istanbul, as Kütüphane Troleybüs, focusing on the relationship between the building's original industrial character and the requirements of its new use. The primary aim of the research is to identify the interventions carried out within the scope of adaptive reuse and to evaluate their effects on the preservation of the building's original features,

the relationship between the new use and the existing structure, and spatial organization.

The data collection process involved on-site observation, photographic documentation, examination of historical and contemporary visual documents, and analysis of architectural plans. On-site observations were conducted during two field visits on April 2, 2026, and May 15, 2026. During these visits, the ground floor and mezzanine floor of the building were examined; original architectural and structural elements, technical equipment, the existing spatial organization, circulation relationships, and interventions carried out as part of the new use were observed and documented photographically. As part of the document analysis, accessible architectural plans and drawings, project information, and historical and contemporary visual documents concerning the historical and current condition of the building were examined. The ground floor and mezzanine floor plans were used to evaluate the current spatial organization; historical and contemporary visual documents were used to assess the historical continuity and original features of the building; and on-site observations, photographs, and current plans were used to identify the interventions carried out.

The data obtained were qualitatively evaluated according to the criteria and indicators defined in Table 1. Under the criterion of preservation of original features, the preservation status of original architectural and technical elements, such as the facade, windows and doors, wall surfaces, steel load-bearing system, technical equipment, and rail system, was examined. Under the criterion of level of intervention/minimum intervention, the relationship of new additions, such as the mezzanine, spiral staircase, side projections, new partitions, and service areas, with the existing building was evaluated. Under the criterion of distinguishability between new interventions and original building elements the ways in which interventions such as new shelves, furniture, railings, glass surfaces, and service areas were physically and visually differentiated from the original building elements were examined. Under the criterion of compatibility between the new use and the existing building, the relationship of the entrance, reading, study, seminar, and service areas with the existing spatial configuration was evaluated. Under the criterion of preservation of the original spatial character, the continuity of the high interior volume, wide spans, gallery void, steel load-bearing system, open-plan layout, and circulation relationships was examined. Under the criterion of spatial and functional flexibility, the ways in which different forms of use, such as individual study, reading, computer use, group work, and seminars, could be accommodated within the existing spatial configuration were evaluated.

Within this scope, no surveys, interviews, or systematic behavioural observations were conducted to directly evaluate user experience, satisfaction, or physical comfort levels. The evaluations were limited to the observable architectural, spatial, and intervention characteristics of the building.

Analytical Evaluation Framework

To ensure that the assessments of the building's adaptive reuse was not based solely on researcher's subjective observations, the analysis process utilized international principles concerning the conservation and adaptive reuse of industrial heritage, as well as evaluation approaches in the current literature. The ICOMOS–TICCIH Dublin Principles (2011) emphasize the preservation of original materials, building components, technical equipment, and spatial relationships in industrial heritage, and highlight that the new use should be integrated in harmony with the values of the building. Furthermore, topics such as originality, minimum intervention, distinguishability of new and old elements, functional

compatibility, and spatial flexibility are prominent in the literature on adaptive reuse (Vafaie, Remøy & Gruis, 2023; Nocca & Remøy, 2026; Xiong et al., 2023).

In this study, three fundamental criteria were considered in the selection of the evaluation criteria. First, the criteria should relate directly to the research aim and research questions; second, they should have counterparts in the literature on the conservation of industrial heritage and adaptive reuse; and third, they should be observable and evaluable through on-site observations, photographic documentation, historical and contemporary visual comparisons, and architectural plans obtained in the study. Accordingly, various evaluation headings in the literature were examined alongside the research questions and the obtained data set; headings that fell outside the scope of the research or could not be directly evaluated using the existing data set were excluded. Interrelated evaluation topics were separated according to the analytical scope of the research, creating a framework that would allow for the examination of the preservation of the case study's original features, the nature of new interventions, and the relationship between the new use and the existing structure.

Table 1. Analytical Evaluation Framework for the Adaptive Reuse Process

Evaluation Criterion	Key Evaluation Indicators	Data Examined in the Case Study
1. Preservation of Original Features	Preservation of original architectural, structural, and technical elements; continuity of original materials, components, and traces of the building (Dublin Principles, 2011; Vafaie et al., 2023; Xiong et al., 2023; Nocca & Remøy, 2026)	The preservation status of the facades, windows and doors, wall surfaces, steel load-bearing system, transformer, rail system, and mechanical equipment, and their continuity as original elements of the building.
2. Level of Intervention / Minimum Intervention	Scope of new interventions in the existing building and their relationship with the original building elements; limiting the impact of interventions on the existing spatial and structural organization (Vafaie et al., 2023; Xiong et al., 2023; Nocca & Remøy, 2026)	The location, scope, and physical impact of the mezzanine, spiral staircase, wet areas, new partitions, side extensions, and other spatial additions on the original building elements.
3. Distinguishability of New and Old Elements	New additions and interventions being distinguishable from the original building in terms of form, material, and construction language (Vafaie et al., 2023; Xiong et al., 2023; Nocca & Remøy, 2026)	The degree to which the spiral staircase, new shelves and furniture, mezzanine railings, glass surfaces, and new service areas are distinguishable from the original building elements in terms of form, material, and construction language.
4. Compatibility Between the New Use and the Existing Structure	Relating the new function to the existing building, spatial organization, and circulation patterns; integrating the new use respectfully with the significant features of the building (Dublin Principles, 2011; Vafaie et al., 2023; Nocca & Remøy, 2026)	The compatibility of the reading and study areas, seminar area, service areas, entrance and consultation area with the existing spatial configuration, high-volume space, open-plan character, and circulation relationships.
5. Preservation of the Original Spatial Character	Preservation of the original volumetric characteristics, openings, structural system organization, open-plan character, and fundamental spatial relationships (Dublin Principles, 2011; Vafaie et al., 2023; Nocca & Remøy, 2026)	The degree to which the high interior volume, wide openings, gallery void, steel load-bearing system, open-plan character, and circulation relationships are preserved and maintained following the new use.
6. Spatial and Functional Flexibility	The ability to accommodate different forms of use within the same spatial configuration; the potential of the existing spatial organization to support different use scenarios (Vafaie et al., 2023; Nocca & Remøy, 2026)	The ability to accommodate different forms of use, such as individual study, reading, computer use, group work, seminars, and shared-use areas, within the existing spatial configuration, and the contribution of the mezzanine to these uses.

As a result of this selection, the evaluation framework was formed by six criteria: preservation of original features, level of intervention/minimum intervention, distinguishability of new and old elements, compatibility between the new use and the existing structure, preservation of the original spatial character, and spatial and functional flexibility. The preservation of original features, along with the compatibility of the new use with the existing structure, is framed according to the Dublin Principles and approaches in the literature on adaptive reuse; minimum intervention and the distinguishability of new and old elements are aligned with the approaches highlighted in the works of Vafaie, Remøy, and Gruis (2023) and Xiong et al. (2023); and spatial and functional flexibility is examined in line with the evaluation topics particularly addressed by Nocca & Remøy (2026). Table 1 shows through which indicators each criterion is evaluated and which specific data from the building are used in the assessment.

RESEARCH FINDINGS

Study Area: Kütüphane Troleybüs

The former Trolleybus Power Center, now known as Kütüphane Troleybüs is located in the Fatih district of Istanbul, around Beyazıt Square and the Süleymaniye area (Figure 1). The building, constructed between 1910 and 1912, was initially used as a stable for horse-drawn trams; in 1914, with the introduction of electric trams, it was expanded and converted into a power station to meet the period's needs. Trolleybus Power Center building served as the Beyazıt Power Station until 1961, and after the termination of tram services, it continued to operate as a power center for the trolleybus system. After trolleybuses were removed from Istanbul's transportation system in 1984, the building remained unused for many years (Cansız, 2024). This structure is one of the most important examples of industrial heritage related to Istanbul's transportation history, bearing witness to the development of the city's electric public transportation systems through its original function and technical infrastructure. Thus, the building is not only a physical example of industrial heritage but also an important memory space relating to Istanbul's transportation history. In 2020, the Istanbul Metropolitan Municipality decided to repurpose the building in line with the needs analysis of the Süleymaniye–Beyazıt region (Cansız, 2024). Accordingly, the Trolleybus Power Center building was adapted for use as a library through interventions carried out by İBB Miras in 2022 and was reopened to the public as Kütüphane Troleybüs (İstanbul Büyükşehir Belediyesi, n.d.).

Historical Development of the Trolleybus System

The trolleybus is a rubber-tired public transport vehicle powered by overhead electric wires that run along a designated route. In this aspect, it is similar to buses but differs in its energy source (Arısal, 2025, p. 4). The historical origins of trolleybus technology date back to the 19th century, with the first application carried out in Berlin in 1882 by Werner von Siemens under the name "Electromote." This development is considered the beginning of electric rubber-tired public transport

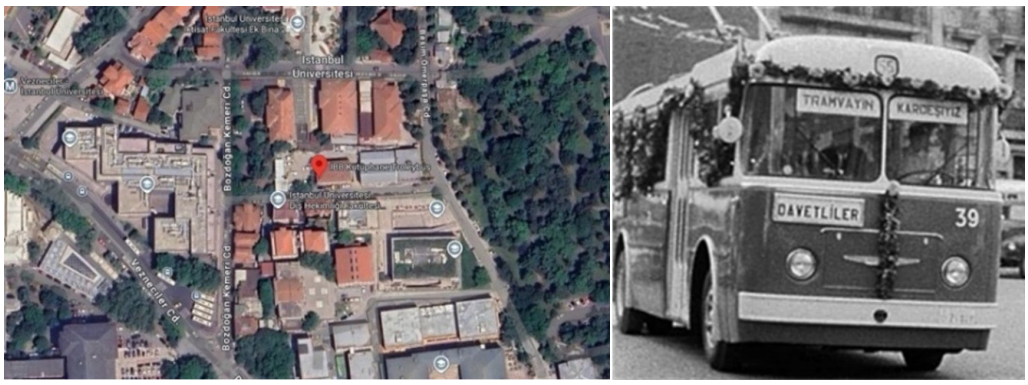


Figure 1. Location of Kütüphane Troleybüs and Image of Trolleybus (Google Maps, n.d.; İstanbul Elektrik Tramvay ve Tünel İşletmeleri, n.d.

systems (Álvarez, 2023). Trolleybus systems expanded rapidly in Europe and North America during the first half of the 20th century. Although their use declined in some regions during the latter half of the century, Rodrigues et al. (2024) report that approximately 300 cities worldwide continue to operate trolleybus systems, with networks across Europe, Asia, and Latin America. (Rodrigues et al., 2024).

Trolleybus systems, which became widespread worldwide, were first introduced in Turkey in 1947 in Ankara, followed by Izmir in 1954. In Istanbul, trolleybuses began operating in June 1961 and served the city's urban transportation system for approximately 24 years. However, due to operational problems such as frequent power outages that disrupted service and stranded vehicles on the road, leading to increased traffic congestion, the system was discontinued in 1984 (Arısal, 2025, p. 4).

History and Architectural Features of the Kütüphane Troleybüs

Today, the Trolleybus Power Center now known as the "Kütüphane Troleybüs," is located in the Süleymaniye neighborhood of Istanbul's Fatih district. After serving Istanbul's transportation infrastructure for many years, the Kütüphane Troleybüs building was reopened for use as a library following restoration work. The building has an area of approximately 520 m² and now includes study areas, bookshelves, multi-purpose spaces, and wet areas; on the mezzanine floor, there are individual study and computer-supported workspaces. Some technical equipment from the building's previous use has also been preserved and is exhibited in the interior (Bozkurt, 2024).

From an architectural perspective, the building reflects the functional design approach seen in early industrial structures. It is built on a skeletal structure that forms the load-bearing system, with brick masonry used for the main walls and stone cladding applied on the exterior facades (Bozkurt, 2024). The main load-bearing system consists of a frame that supports both the roof and the walls. This structural system allows for the creation of large spans required by the building's technical function. The original spatial layout of the building was shaped according to its role in serving energy and transportation infrastructure. The wide and high-volume interior space offers an open-plan layout suitable for the placement of technical equipment. Thanks to the large window openings, the building benefits from natural lighting and reflects the characteristic features of industrial architecture, where functional requirements are prioritized. These features are important spatial advantages that have facilitated the adaptive reuse of the Kütüphane Troleybüs building for different function.

The arched openings at the top of the windows are among the important architectural elements that strengthen the building's facade character. The stone cladding on the facade was cleaned and preserved during the restoration, thereby maintaining the visibility of the original details that define the building's historical identity. In addition, maintenance and preservation work were carried out on the wooden doors and window frames on the facade to preserve the building's character (Bozkurt, 2024).

Inside, the wide and high-volume spatial character typical of the industrial use period has been preserved. The building's steel roof system, visible load-bearing elements, and exposed technical components support the readability of its industrial identity. New load-bearing elements added during the restoration were implemented in different colors to distinguish them from the existing system, enabling users to perceive the relationship between the original structure and later interventions. The mezzanine floor added to the Kütüphane Troleybüs

building was also constructed using this secondary structural system and was designed to meet the spatial requirements of the new use (Bozkurt, 2024).

Overall, the Trolleybus Power Center stands out as an important example of industrial heritage related to Istanbul's transportation infrastructure, with its structural features, material use, and original spatial organization. The fact that the building's original architectural character has been largely preserved during its adaptive reuse has enabled it to sustain its historical identity alongside current use requirements (Bozkurt, 2024).

Adaptive Reuse of the Kütüphane Troleybüs
Transformation process of the building

To reveal the spatial organization of the building in its current library use, the ground floor and mezzanine floor plans were examined (Figure 2). The plan analysis includes the distribution of areas created within the framework of the library function, circulation relationships, vertical connections, and spatial arrangements.

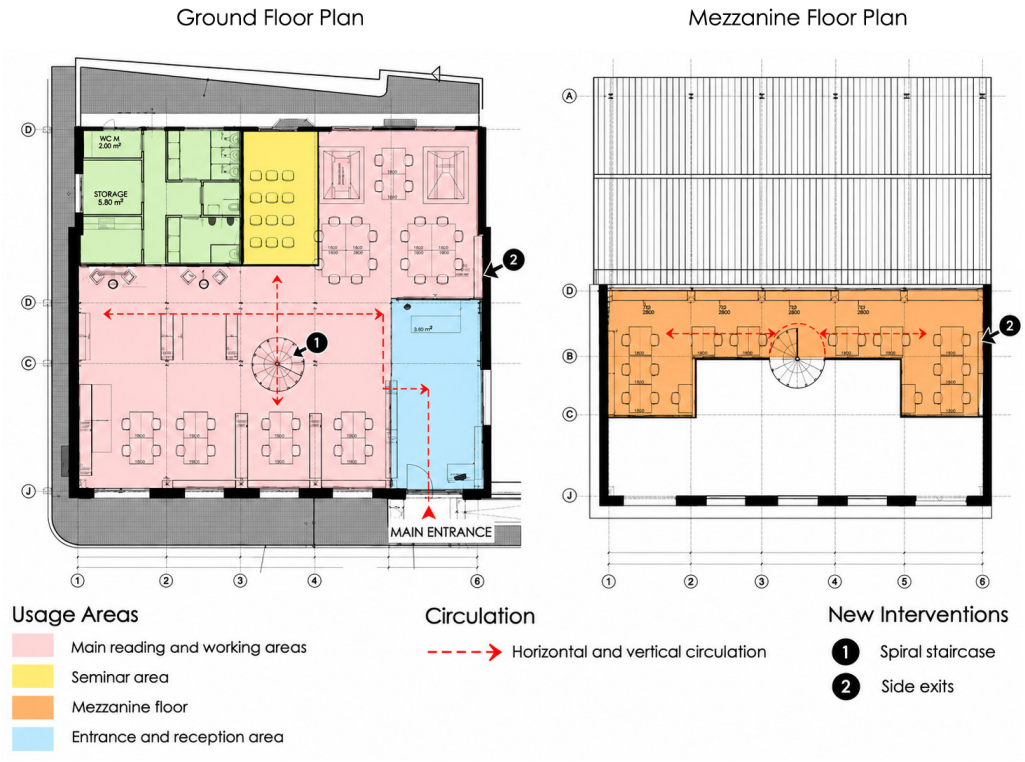


Figure 2. Kütüphane Troleybüs Floor Plans (Floor plans adapted by the author from Cansız, 2024.)

When the plans are examined, it is observed that the entrance floor includes entry and reception, main reading and study areas, a seminar area, and service areas, while the mezzanine includes areas for individual study and computer use. The reception area includes an information and consultation desk and directional functions and is organized as the section providing access to the main use volume.

The main use area, located at the center of the building, is designed as a large space where the main activities of the library function take place. This area accommodates individual study, reading, research, and computer use. Shelving systems and work tables are used to create different study and reading areas within the main use volume.
The seminar area, organized in connection with the main use area, is designated for group work, discussions, and activities requiring verbal communication. Wet

areas and service areas are located at the rear of the building to serve different functions.

On the upper level, the mezzanine includes areas for individual study and computer use. The visual relationship between the mezzanine and the main use area is established through the spatial arrangement around the gallery void, creating both vertical and visual connections between the entrance floor and the mezzanine.

Conservation and intervention approaches to the building's surroundings and façade

As shown in the comparative visuals presented in Figure 3, the building was historically located in an area predominantly consisting of green space, whereas today it is surrounded by an urban fabric characterized by hard-surface arrangements, pedestrian paths, urban furniture, and landscaping elements. This change reveals the transformation of the building's environmental context over time.

The informational panels located around the building are new arrangements that facilitate the communication of information about the building's historical background and industrial character to users. Industrial heritage includes not only physical components but also values related to past use, technical knowledge, and collective memory, and making these values visible constitutes part of the conservation approach (ICOMOS–TICCIH, 2011). From this perspective, the informational panels can be considered interpretive elements that convey information about the building's past use within the new public function.
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The comparison of the past and present facade visuals in Figure 3 shows that the fundamental architectural elements constituting the facade have largely been preserved. The semi-circular arched window openings, window arrangements, and window frames have been maintained, while the decorative tile motifs

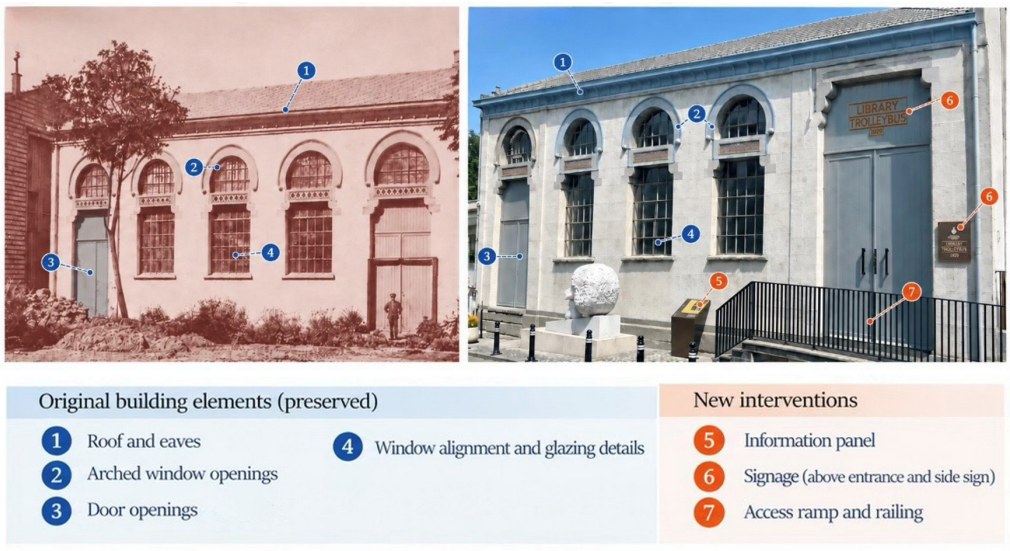


Figure 3. Comparison of the Kütüphane Troleybüs Past and Present Surroundings and Facade Condition (Karay, 2022; Author's Archive, 2026).

above the arches have also been preserved. Similarly, the existing door openings and door leaves have been addressed through cleaning and maintenance interventions while preserving their original features. The preservation of these elements ensures the continuity of the building's original architectural character and the historical traces associated with the facade. The preservation of materials, structural components, and physical traces in industrial heritage buildings is considered fundamental to sustaining the cultural values of the building (ICOMOS–TICCIH, 2011; Nocca & Remøy, 2026).

In addition, new arrangements have been made around the entrance and facade in response to the accessibility and identification requirements of the new use. A ramp has been added to support accessibility to the entrance area, and new signage and informational elements related to the new use have been placed on the building's facade. These interventions can be evaluated as physical additions made during the adaptation of the existing structure to the requirements of the new use. In the adaptive reuse literature, it is emphasized that the impact of interventions required by the new use on the original components of the existing building should be limited and that interventions should be kept to a minimum extent possible. (Vafaie, Remøy, and Gruis, 2023; Nocca & Remøy, 2026).

The differentiation of new elements added to the facade and entrance area from the existing original elements is also significant for the readability of the interventions. New additions being distinguishable from the original structure in terms of form, material, or construction language supports the differentiation of past and contemporary interventions and contributes to the preservation of the historical layers of the building (Vafaie, Remøy, and Gruis, 2023; Xiong et al., 2023). In this regard, the ramp, signage, and informational elements added to the facade are perceived as contemporary interventions that differ from the original facade components.

Overall, the comparative visuals in Figure 3 demonstrate that changes have occurred in the spatial arrangement of the building over time; however, the fundamental architectural elements forming the facade have largely been preserved while modifications required by the new use have been added to the structure. These findings indicate that the facade interventions can be examined through the preservation of original features, limitation of the level of intervention, and distinguishability of new additions from the original structure.

Spatial and structural interventions on the building

It can be observed that the spatial arrangements required by the new use have been implemented largely while preserving the existing steel load-bearing



Figure 4. Steel Spiral Staircase of the Building: 1 – Metal Railing System; 2 – Spiral Staircase (Author's Archive, 2026)

system of the building. The preservation of the existing load-bearing system is important for the continuity of the building's original structural character.

In industrial heritage buildings, the preservation of original structural components and technical characteristics is considered fundamental to sustaining the historical and industrial values of the structure (ICOMOS–TICCIH, 2011; Nocca & Remøy, 2026). In this regard, the preservation of the existing steel load-bearing system stands out as an approach emphasizing interventions based on the existing structural character.

One of the notable additions associated with the new use is the steel spiral staircase located at the center of the building (Figure 4). The material and geometric form of the staircase distinguish it from the existing structural elements, making the new intervention distinguishable.

The distinguishability of new additions from the original structure in terms of form, material, or construction language is important for enabling the legibility of past and current interventions and for understanding the historical development of the building (ICOMOS, 1964; Vafaie, Remøy, & Gruis, 2023; Xiong et al., 2023). In this respect, the spiral staircase functions as a contemporary intervention, making the relationship between the original structure and the new use visible. However, the absence of an elevator in the building and reliance on stairs for access to the mezzanine constitute a limitation that needs to be considered in terms of vertical access in the current use of the building.

Other spatial interventions associated with the building's new function include the mezzanine created by taking advantage of the existing floor height and side projections. The positioning of the mezzanine in relation to the window openings at the upper level demonstrates that the new arrangement has been integrated with the existing facade openings. Together with the side projections, this arrangement enables the building's large volume to be used for different functional areas. The section analysis (Figure 5) reveals that the original high interior volume and steel load-bearing system have been preserved while a new mezzanine and vertical circulation elements have been established using the existing volume.

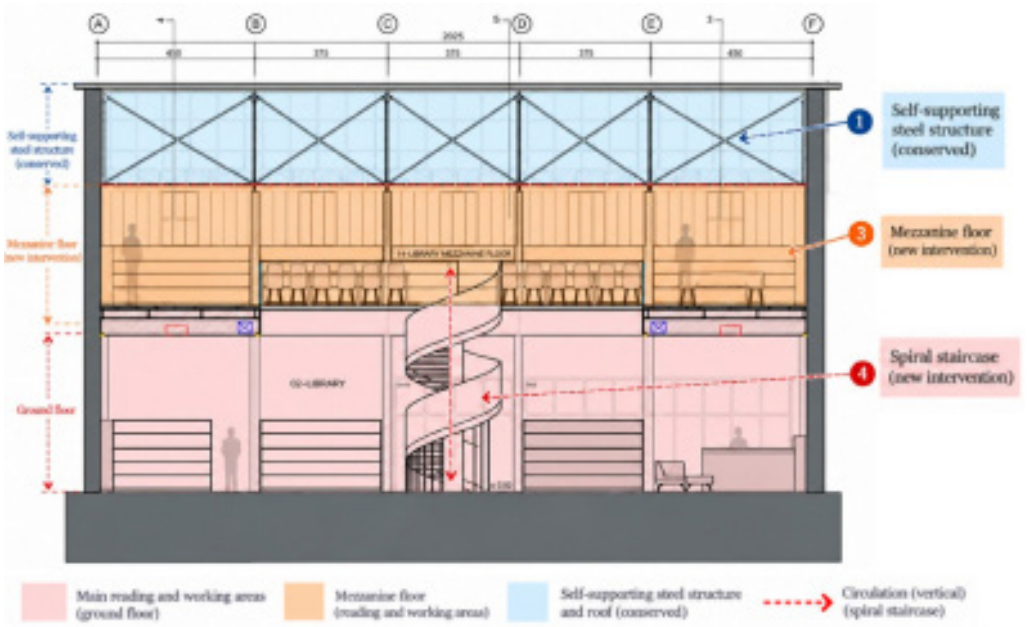


Figure 5. Representation of the Preservation of the Original Load-Bearing System and New Spatial Interventions through the Existing Section of the Building (Section adapted by the author from Cansız, 2024.)



Figure 6. Spatial Interventions to the Mezzanine Before and After the Adaptive Reuse of the Building (Image displayed on the information panel at the entrance of Kütüphane Troleybüs; photographed by the author, 2026. Author's Archive, 2026).

The position of the mezzanine and side projections within the main space and their relationship with the existing structure can be comparatively observed in the visuals presented in Figure 6 before and after adaptive reuse.

In line with the library function, work tables, shelving systems, and different functional units have been placed in the main use area (Figure 7). Thus, areas for various activities such as reading, research, individual study, and shared use have been created within the same main volume. The work areas located at the rear of the building have been organized as a distinct use zone separate from the main use area. Additionally, areas for work and research activities have been created on the mezzanine, distributing use areas between the entrance floor and the upper level.

The open gallery void that maintains the visual connection between the mezzanine and the main space ensures the continuity of the spatial relationship between the upper and lower levels. Similarly, the positioning of areas for seminars and group use in a different part of the main work volume demonstrates an arrangement that accommodates different types of use within the same structure. The coordination of different functional areas within the same building is significant in terms of the spatial and functional flexibility discussed in the literature on adaptive reuse (Nocca & Remøy, 2026).

The added wet areas are also part of the new spatial arrangements required by the library function. As shown in Figure 7, these areas are positioned at the rear of the building, differentiating them from the main use areas. The concentration of wet areas in a specific section creates an arrangement aimed at separating service functions from the main reading and work areas. The resolution of the service functions required by the new use within a specific area of the existing structure can be evaluated in terms of the relationship established by the intervention with the existing organization. In adaptive reuse projects, it is emphasized that the new use should be addressed in a manner that respects the significant spatial features and circulation relationships of the existing structure (ICOMOS–TICCIH, 2011; Vafaie, Remøy, and Gruis, 2023).

In general, the preservation of the existing steel load-bearing system in the spatial and structural interventions of the building, the contemporary addition of a new vertical circulation element, the creation of a mezzanine utilizing the high volume, and the distribution of different use areas suitable for the library



Figure 7. Spatial Interventions Related to the Main Use Area of the Building: 1–Work Area; 2–Entrance Floor; 3–Wet Area Corridor (Author's Archive, 2026)

function within the structure stand out. These interventions demonstrate that the existing structural and spatial features are preserved while the requirements of the new use are addressed simultaneously.

Entrance, circulation, and spatial organization of the building

The entrance area of the building serves as a starting space where original architectural elements are combined with the necessary adjustments for the new library function. The original form of the entrance door has been preserved, and it has been restored for reuse through cleaning and maintenance interventions (Figure 8). The reception desk located at the entrance serves to welcome and inform visitors in line with the library function. The partially permeable shelving system positioned between the entrance and the main use area creates a physical division between the two spaces. The permeable structure of the shelving system allows usage boundaries to be defined without completely separating the entrance area from the main space.



Figure 8. The Kütüphane Troleybüs Entrance and Reception Area; Entrance Door and Information Desk (Author's Archive, 2026).

One of the arrangements in the entrance area is the glass surfaces created in the floor, which reveal traces of the building's previous uses (Figure 9). By preserving the floor voids housing original infrastructure systems and covering them with walkable glass panels, these elements can be read alongside the existing space rather than being hidden within the new use. Thus, the technical traces of the building's past uses persist not only as exhibited objects but also as spatial components encountered within the circulation area. In the evaluation of industrial heritage, the preservation of technical components,

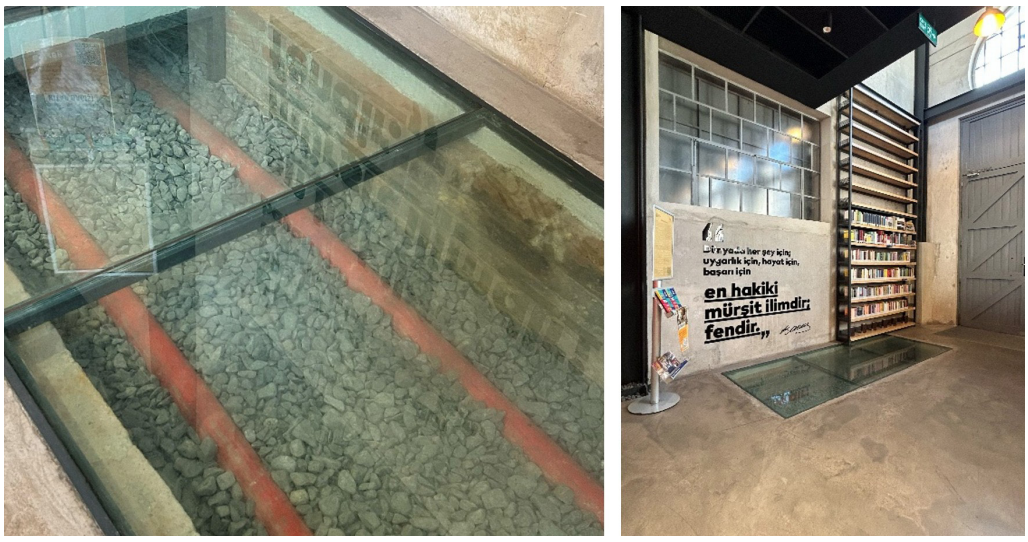


Figure 9. Glass Surfaces Used in the Kütüphane Troleybüs Entrance Area (Author's Archive, 2026)

machinery, equipment, and their associated physical traces is considered part of maintaining the building's value (ICOMOS–TICCIH, 2011).

The lighting and furnishing elements used in the entrance and main use areas are contemporary spatial components created within the framework of the new function. Pendant lights have been used at the reception desk and along the entrance axis, while surface-mounted spotlights have been installed under the mezzanine. Additionally, exposed ventilation ducts and mechanical installation elements are visible alongside the existing load-bearing system. The use of steel, wood, and glass materials in the new furnishing elements, together with the preserved concrete, wall, and steel surfaces, allows architectural and furnishing components from different periods to be read within the same spatial integrity. The main spatial organization of the building develops around a high-volume central area (Figure 10). Large window openings, the visible load-bearing system, and preserved wall surfaces constitute the fundamental spatial characteristics of this area, while shelving systems designed for the library function are used to define use zones within the existing open plan.



Figure 10. The Main Space of the Kütüphane Troleybüs; Shelving Systems and Preserved Wall Surfaces (Author's Archive, 2026).

Shelves located along the window sills and on the central axis separate different use areas without completely dividing the space. In particular, the accessibility of the shelves on the central axis from two directions indicates that these elements are used not only for storing books but also for defining spatial organization and circulation.

In this arrangement, circulation is shaped not by closed partitions but by the existing openings and the locations of the shelving systems. Keeping the main use area open allows different working and reading zones to establish relationships within the same volume, while the specific positioning of the shelves delineates the boundaries of the use areas. Thus, the spatial distinctions required by the library function are created through furnishing elements rather than by completely dividing the existing space. The consideration of the existing spatial

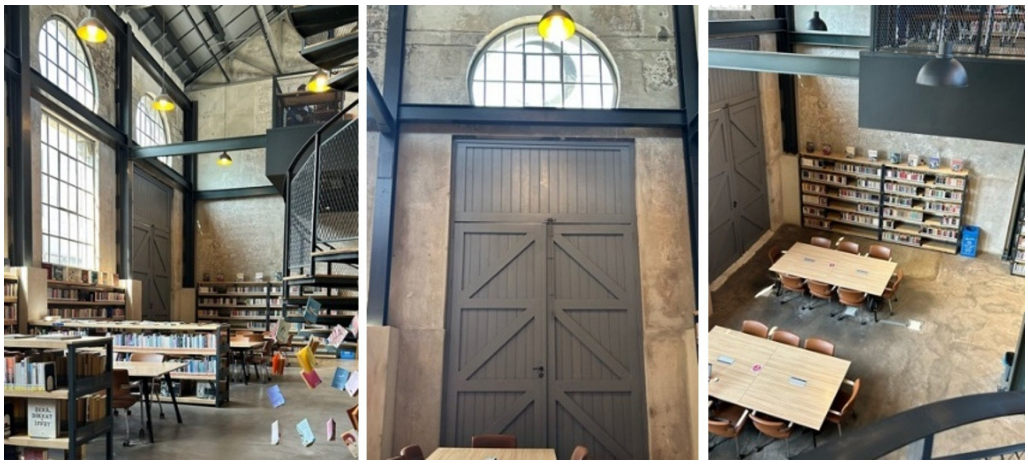


Figure 11. The Second Door of the Kütüphane Troleybüs (Author's Archive, 2026).

relationships and circulation patterns in the new use is also significant in the conservation approach to the adaptive reuse of industrial heritage structures (ICOMOS–TICCIH, 2011). The second large door located within the main space, although not actively used today, has been preserved (Figure 11).

The current non-functional status of the door, together with its preservation, indicates that elements from the previous period of use continue to exist within the new organization. The preservation of such elements shows that existing structural components not required by the new use are maintained within the space as part of historical continuity. In the rear section of the main use area, various arrangements for individual and collective use coexist (Figure 12). While desks and seating elements are organized for individual work and computer use, the section with screens and seating arrangements is designated for seminars, presentations, and group work.



Figure 12. Spatial Organization in the Rear Section of the Kütüphane Troleybüs; Study Area, Collective Study Area, and Preserved Transformer Power Source (Author's Archive, 2026).

Thus, different modes of use are accommodated not in completely separate spaces but within different sections of the same overall organization. This situation illustrates that various use scenarios are addressed within the same spatial system during the adaptation of the existing structure to its new library function.

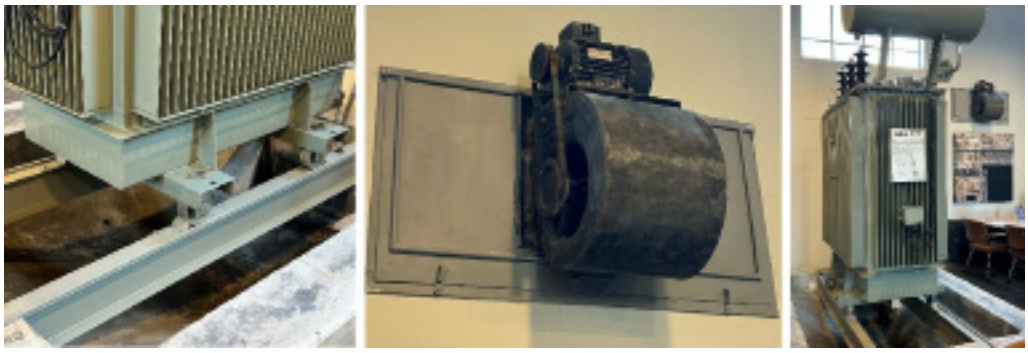


Figure 13. Preserved Mechanical Equipment in the Kütüphane Troleybüs; Original Rail Transport Arrangement, Siemens Electric Motor, and Transformer Belonging to AEG-ETİ Company (Author's Archive, 2026).

Technical traces related to the building's industrial past continue to exist in the main use area through the preserved transformer power source, original rail transport system, and mechanical equipment (Figure 13). The preservation of the original rail transport arrangement of the transformer system allows the equipment to be read not merely as an individual object but as a component related to the building's previous technical operation. Mechanical equipment parts and ventilation elements left on the wall surfaces also maintain traces of the building's technical infrastructure. Keeping these elements visible in the new use indicates that the physical layers related to the building's industrial past are not entirely relegated to the background in the current spatial organization. The preservation of original machines, equipment, and technical components of industrial heritage is crucial for sustaining the historical and technological values of the structure (ICOMOS–TICCIH, 2011).

Overall, in the entrance, circulation, and spatial organization of the building, the preservation of existing openings and the definition of use areas required by the library function within those openings stand out. The preservation of the original door at the entrance, the use of shelving systems to define spatial boundaries instead of closed partitions, and the visibility of technical equipment indicate that the physical traces related to the building's past continue to exist within the new use. Conversely, the reception desk, shelves, work furnishings, and lighting elements constitute the current spatial components required by the new function. This integration shows that instead of completely transforming the existing spatial character of the building, the new use is organized through the existing spatial and technical features.

DISCUSSION

The findings obtained within the scope of the study were discussed in accordance with the evaluation criteria defined in the methodology section and compared with relevant international adaptive reuse examples. Table 2 presents the relationship between the findings concerning Kütüphane Troleybüs and the specified evaluation criteria. This evaluation focuses on the relationship between the preservation of the building's original features and the interventions required by its new use. Subsequently, the findings for Kütüphane Troleybüs were compared with LocHal Library, Tate Modern, and the Large Machine Factory, which represent different approaches to adaptive reuse. LocHal Library provides a basis for comparison in terms of relating existing industrial spaces to new library

Table 2. Analysis of Kütüphane Troleybüs According to the Evaluation Criteria

Evaluation Criterion	Case Findings	Assessment
1. Preservation of Original Features	Preservation of the steel load-bearing system, facade and door elements, wall surfaces, as well as the transformer, rail transport system, and mechanical equipment	The preservation of architectural, structural, and technical components together supports the continuity of different physical layers related to the building's industrial past.
2. Level of Intervention / Minimum Intervention	Addition of the mezzanine, spiral staircase, side projections, and new service areas while preserving the existing load-bearing system	Despite the addition of a mezzanine, spiral staircase, side projections, and service areas required for the new use, the main load-bearing system and fundamental spatial features have been preserved. Although this indicates that the interventions were developed through the existing building, it does not in itself demonstrate that the principle of minimum intervention has been fulfilled. Therefore, minimum intervention was evaluated based on the observable physical relationship between the location and scope of the new additions and the original building elements.
3. Distinguishability of New and Old Elements	Differentiation of the spiral staircase, new furnishing elements, and glass surfaces from the original building elements	The differentiation of new elements from the original elements through their formal and material characteristics supports the readability of interventions from different periods within the space.
4. Compatibility Between the New Use and the Existing Structure	Organization of the library function within the existing high volume, wide openings, and open spatial organization	The use of the existing spatial and structural features by the new function indicates that a compatible relationship has been established between the function and the building.
5. Preservation of the Original Spatial Character	Preservation of the high volume, wide openings, visible steel load-bearing system, and open plan	Despite the arrangements required by the new use, the building's distinctive volumetric and spatial features continue to exist.
6. Spatial and Functional Flexibility	Creation of different areas for individual study, reading, computer use, seminars, and group work	The ability to accommodate different forms of use within the same overall spatial configuration indicates the potential of the existing spatial organization to support different use scenarios. However, this does not in itself demonstrate the building's convertibility to different functions or its capacity for future adaptation; rather, it indicates that diversity of use can be accommodated within the same spatial framework under the existing library function.

Table 3. Comparative Analysis of Kütüphane Troleybüs and International Adaptive Reuse Examples

Evaluation Criterion	Kütüphane Troleybüs	LocHal Library	Tate Modern	The Large Machine Factory
Preservation of the Original Building and Its Values	Preservation of architectural, structural, and technical components together; continuation of physical traces of the industrial past	Relating original industrial spaces to new library and cultural functions	Evaluation of the industrial spatial characteristics of the existing building within its new use	Preservation of original architectural and structural features together with materials and building elements reflecting the historical character
Intervention Approach	Addition of interventions required by the new function while preserving the existing load-bearing system and fundamental spatial features	Use of contemporary additions related to the existing building	Strengthening the spatial potential of the existing building with new architectural components	A light intervention approach; limiting the impact on the original structural and mechanical systems and implementing new reinforcements as independent systems
Relationship Between New and Existing Elements	New interventions are differentiated from the original building elements in terms of form and material	Relating contemporary additions to the existing building and emphasizing their character	An approach that establishes unity between old and new elements	New or altered elements are distinguishable from the original building

and cultural functions and incorporating contemporary additions; Tate Modern offers a basis for evaluating the spatial potential of an existing building within a new cultural function; and the Large Machine Factory provides a basis for examining authenticity, minimum intervention, and the distinguishability of new

Table 4.

Evaluation Criterion	Kütüphane Troleybüs	LocHal Library	Tate Modern	Large Machine Factory
Intervention Approach	Addition of interventions required by the new function while preserving the existing load-bearing system and fundamental spatial features	Use of contemporary additions related to the existing building	Strengthening the spatial potential of the existing building with new architectural components	A light intervention approach; limiting the impact on the original structural and mechanical systems and implementing new reinforcements as independent systems
Relationship Between New and Existing Elements	New interventions are differentiated from the original building elements in terms of form and material	Relating contemporary additions to the existing building and emphasizing their character	An approach that establishes unity between old and new elements	New or altered elements are distinguishable from the original building
Relationship Between New Use and Existing Building	Resolving the library function within the existing spatial configuration	Relating existing industrial spaces to library and cultural uses	Evaluating the spatial potential of the existing building in a way that supports its new artistic use	Arranging new functions to benefit from the characteristics of the existing large-scale space
Spatial Character	Preservation of the high-volume space, wide spans, exposed steel structural system, and open-plan layout	Wide spans enabling flexible and diverse uses	The building's large-scale, raw spatial character and robust structure creating potential for new use	Preserving the large and open industrial space and making the original interior structure legible in the new use
Diversity of Use / Flexibility	The ability to accommodate different forms of use, such as individual study, reading, computer use, seminars, and group work, within the same overall spatial configuration	Creation of spaces that accommodate conferences, public events, and various activities in addition to the library function	Evaluation of the large-scale existing space for different art events and uses	Preservation of the large industrial space, allowing for future adaptive reuse

interventions (Sedes & Mumcuoğlu, 2023; Shin, 2025; Xiong et al., 2023). These comparisons are summarized in Table 3 according to the evaluation dimensions, while the findings concerning Kütüphane Troleybüs are discussed in detail in relation to these examples in the following subsections.

Preservation of original features

The assessment of originality in industrial heritage structures is not limited to the preservation of architectural elements belonging to the building's initial design. Technical equipment, traces related to production or operational processes, the building system, and the relationships among these elements also constitute parts of originality. The ICOMOS–TICCIH Dublin Principles define the value of industrial heritage not only through the building itself but also through its material texture, components, machines, and the relationships established with its surrounding environment. Therefore, the continuity of originality after adaptive reuse can be evaluated not only through the preservation of individual elements but also through the ability to read different layers representing the building's past use together.

This approach is in a similar direction to the evaluation framework proposed for the preservation of authenticity in the Large Machine Factory case. Xiong et al. (2023) relate the preservation of authenticity in the adaptive reuse process to understanding the functional, structural, and façade characteristics of the building, preserving its significant features, and implementing interventions in ways that do not undermine these values. The study also considers minimal intervention and interpretability among the key principles for maintaining authenticity (Table 3).

For Kütüphane Troleybüs, this comparison demonstrates that originality cannot be explained solely through the preservation of the building's exterior appearance. The continuation of architectural features together with technical and structural layers suggests that the industrial past of the building has not been completely erased within the new use. Thus, originality in the Kütüphane Troleybüs gains meaning through the preservation of the readability of physical traces related to its past use within the current function.

Level of intervention and minimum intervention

The principle of minimum intervention should not be reduced to a one-dimensional criterion defined as intervening in the building as little as possible during the adaptive reuse process. Completely eliminating the interventions required by the new use is often not possible, and the amount of intervention alone is not sufficient to explain the level of preservation of the building. What is more important here is the nature of the relationship established between the interventions and the values carried by the building. While the Dublin Principles recognize adaptive use as an important tool for the conservation of industrial heritage, they emphasize that the new use should respect significant materials, components, and existing circulation relationships.

In the Large Machine Factory example, minimum intervention is considered together with the preservation of originality and the relationship of new interventions to the fundamental character of the building (Xiong et al., 2023). In the Tate Modern example, utilizing the potential of the existing building and evaluating its possibilities are important rather than creating an unnecessary spatial transformation for the new use (Shin, 2025). When these two approaches are considered together, minimum intervention can be understood not simply as "less intervention," but as an approach that keeps new interventions at the

necessary level by making use of the possibilities of the existing building as much as possible (Table 3).

The findings from the Kütüphane Troleybüs indicate that the adaptive reuse interventions were shaped in accordance with the characteristics and values of the existing building. Despite the additions required by the new use, the preservation of the building's fundamental structural and spatial features demonstrates that the transformation was carried out by utilizing the possibilities of the existing building rather than reconstructing it entirely. However, this finding alone does not demonstrate that the principle of minimum intervention has been fulfilled. In Kütüphane Troleybüs, minimum intervention was evaluated not through the quantitative measurement of interventions or engineering assessments of their structural performance, but through the observable spatial and physical relationships between the location and scope of new additions and the original building elements.

Distinguishability of new and old elements

The distinguishability of new and old elements after adaptive reuse is important for enabling the different historical layers of a building to be read without becoming mixed together. This approach allows new interventions to express their own period rather than imitate the original building. Thus, the building can be read not only as a single period belonging to the past but also through the transformations it has undergone over time.

In the Large Machine Factory study, the preservation of originality is associated with the distinguishability of new interventions from the existing characteristics of the building and with the interpretability of these interventions (Xiong et al., 2023). In this context, what is important is not the complete separation of new additions from the historical building, but the ability to understand which elements are original and which are later interventions (Table 3).

When the new interventions in Kütüphane Troleybüs are evaluated within this framework, the fact that contemporary additions have formal and material characteristics that do not imitate the original elements contributes to the reading of different periods of the building together. Thus, the new use is expressed as a contemporary layer of the building rather than being concealed as part of the historical structure. This can be interpreted as a design approach that enhances the legibility of the relationship between the original building elements and new interventions without compromising the building's originality.

Compatibility between the new use and the existing structure

The compatibility between the new use and the existing structure refers to a more comprehensive relationship than simply placing the spaces required by the new function within the building. What is decisive is how the new use makes use of the spatial and structural possibilities of the existing building and to what extent it transforms these possibilities. The Dublin Principles state that adaptive use is an important conservation tool for industrial heritage structures and that new uses should respect significant materials, components, and circulation patterns.

The LocHal, which was converted to a library, provides a direct basis for comparison in this regard. Sedes and Mumcuoğlu (2023) examine the relationship between the original spaces of the industrial building and the requirements of the new cultural function, as well as the role of contemporary additions within this relationship. The evaluation of the existing industrial spaces for the new function emerges as a fundamental approach in the study (Table 3).

The main commonality between Kütüphane Troleybüs and LocHal is that the library function is developed through the possibilities of the existing industrial volume rather than by creating a new building configuration. However, the forms of use in the two examples are not the same. While the large industrial volume of LocHal is transformed into a multi-purpose program that also supports different activities and public uses, the Kütüphane Troleybüs emphasizes the resolution of the library program within the existing spatial organization (Sedes & Mumcuoğlu, 2023). This comparison shows that compatibility can be established not simply by directly transferring a specific function into a building, but by relating the new use to the possibilities offered by the existing building (Table 3).

Preservation of the original spatial character

Preservation of the original spatial character refers to the continuity of the building's scale, volumetric integrity, and fundamental spatial relationships, rather than merely the preservation of individual building elements. Therefore, even when the materials or facade elements of a building are preserved, an adaptive reuse process may completely eliminate its original spatial character. The preservation of spatial character therefore enables originality to be evaluated at a more holistic level.

Tate Modern provides an important comparison in this regard. The study concerning the conversion of Bankside Power Station for cultural use indicates that the large-scale spatial quality of the existing building constitutes an important potential for the new use and that the interventions are related to this potential (Shin, 2025). Similarly, in Kütüphane Troleybüs, the new use is not based on a spatial division that completely eliminates the existing volumetric characteristics of the building.

When the two examples are considered together, the preservation of spatial character does not mean limiting all changes required by the new function. Rather, it is important that the new use benefits from the characteristic spatial features of the building instead of eliminating them. Thus, the spatial qualities resulting from the building's previous use become not only elements that need to be preserved but also an existing resource used in establishing the new use.

Spatial and functional flexibility

Spatial and functional flexibility is addressed in this study not only in terms of the ability of the adaptively reused building to meet its current use requirements, but also in terms of its capacity to accommodate different forms of use within the same spatial framework. Therefore, the source of flexibility does not always lie in the addition of new spaces. The scale, openings, and spatial organization of the existing building can also create a capacity to support different use scenarios.

In this respect, the LocHal example provides a meaningful basis for comparison with the Kütüphane Troleybüs. In the study by Sedes and Mumcuoğlu (2023), the large industrial space of LocHal is associated not only with its library function but also with uses that accommodate different events and public activities. This indicates that the large and open spatial characteristics of industrial buildings can create the potential to accommodate different activities following adaptive reuse (Table 3).

For Kütüphane Troleybüs, however, the main source of flexibility lies not in the continuous addition of new spaces but in the ability of the existing spatial configuration to accommodate different forms of use. Therefore, the flexibility referred to here does not necessarily mean that the building can be converted to a different function in the future. Rather, it is evaluated in a more limited

and measurable manner as the ability to accommodate different use scenarios within the existing library program and the same spatial framework.

CONCLUSION

This study examined the adaptive reuse process of the Trolleybus Power Center, located in Beyazıt, Istanbul and currently used as the Kütüphane Troleybüs, through the relationship between the building's original architectural, structural, and technical features and the spatial arrangements required by the new library function. The evaluations demonstrated that the fundamental features constituting the building's industrial identity have been preserved during the adaptive reuse process, while the interventions required by the new use have been implemented in relation to the existing spatial configuration. In this respect, Kütüphane Troleybüs presents a distinctive example of bringing a disused transportation infrastructure building into contemporary public use through conservation and adaptive reuse.

In the adaptive reuse of the building, the conservation approach should not be limited to the facade and architectural elements. The continued presence of the load-bearing system and technical elements related to the building's industrial operation supports the legibility of physical traces associated with the building's past within its current use. In addition, the differentiation of new interventions from the original building elements through their formal and material characteristics allows the different periods of the building to be distinguished from one another. Thus, in Kütüphane Troleybüs, a relationship has been established between the past and contemporary use by balancing the preservation of existing values with the accommodation of new requirements, rather than either fixing the building's originality entirely or reconstructing the building according to its new function.

Resolving the library function within the existing high-volume space, wide spans, and open spatial organization indicates that the building's original spatial character has been considered an opportunity rather than a constraint for the new use. The ability to accommodate different forms of use, such as working, reading, computer use, seminars, and group work, within the same overall spatial configuration indicates the potential of the existing spatial organization to support different use scenarios. However, this does not in itself demonstrate the building's convertibility to different functions or its capacity for future adaptation. Therefore, spatial and functional flexibility in this study was evaluated not in terms of the capacity to convert the building to a different function, but in terms of the ability to accommodate different forms of use within the same spatial framework under the existing library function. This finding indicates that developing new uses for industrial heritage buildings based on their existing spatial capacity may contribute to establishing a balance between the preservation of heritage values and the requirements of contemporary functions.

However, the positive characteristics of the adaptive reuse process in terms of the relationship between conservation and new use do not mean that the building has no limitations with regard to current use requirements. In particular, the absence of an elevator constitutes a significant limitation in terms of accessibility. Providing vertical access only by stairs may restrict users with mobility limitations from accessing different levels and areas of the building. Therefore, in the adaptive reuse of industrial heritage buildings, it is important to consider the preservation of the original spatial character together with current accessibility requirements. Kütüphane Troleybüs example also demonstrates that conservation decisions should be evaluated not only in terms of maintaining

existing historical and architectural values, but also in relation to the accessibility conditions required by the building's current public use.

The main contribution of the study is to examine adaptive reuse interventions in an industrial heritage building associated with transportation infrastructure through evaluation criteria highlighted in the literature, thereby demonstrating the relationship between conservation, intervention, and new use through a concrete case. The comparison with the LocHal Library, Tate Modern, and Large Machine Factory examples has enabled the interventions at Kütüphane Troleybüs to be interpreted not only in relation to the specific case, but also within the framework of approaches such as originality, level of intervention, distinguishability, compatibility, and spatial potential that are prominent in the adaptive reuse of industrial heritage. Accordingly, the study provides a case-based evaluation of the relationship between industrial heritage buildings associated particularly with transportation and energy infrastructure and new public functions.

The limitation of the study is that the evaluations are confined to data obtained through literature review, on-site observation, photographs, and comparisons of existing and historical plans and drawings. User interviews, systematic observation of user behaviour, and measurements related to acoustic, lighting, and indoor environmental conditions were not included within the scope of the research. Therefore, the results were interpreted based on the observable architectural, spatial, and intervention characteristics of the building rather than user experience or its capacity for future functional change. Future studies examining the accessibility experiences of different user groups, user behaviours, and indoor environmental conditions, as well as comparatively addressing similar transportation infrastructure buildings, may enable more comprehensive evaluations of the adaptive reuse of industrial heritage buildings.

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In this research, the necessary permissions were obtained from the relevant participants (individuals, institutions and organizations) during the survey, indepth interview, focus group interview, observation or experiment.

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Research Article

Universal Design in Montessori Kindergarten Design: Analysing The Benefits of Montessori Kindergarten Design for All Children

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Abstract

Educational inequality is a worldwide challenge, highlighting the need for alternative learning environments that provide equitable access and meaningful participation for diverse learners. Montessori is a well-established example of a developmentally beneficial approach, which is a model of the high-fidelity pedagogy, but requires accurate architectural translation. There is an important research gap due to the lack of an integrated architectural framework that systematically combines Montessori pedagogy (e.g., the Prepared Environment and Autonomy) with Universal Design principles, despite their strong theoretical synergy. This study employed a qualitative framework-development methodology based exclusively on secondary evidence, comprising a systematic literature review, secondary comparative architectural case study analysis, and design framework synthesis. The study did not involve primary data collection from users or experts; therefore, the proposed framework represents a theoretically and analytically derived model that requires further empirical validation. The main output is the Universal Montessori Kindergarten Design Framework (UMKDF), which has four verifiable layers: theoretical Inputs (Pedagogical and Accessibility principles); Spatial Translation Mechanisms (e.g., Kinetic Planning); a Design Control System (measurable architectural outputs); and a Risk Management Layer to mitigate functional failures like noise stress and accessibility breakdowns. The UMKDF provides a theoretically and analytically derived architectural framework for identifying and addressing key spatial conflicts between Montessori autonomy, universal accessibility, sensory regulation, and risk control. Its practical effectiveness requires further empirical validation through stakeholder evaluation and post-occupancy studies.

Keywords: Design Framework, Early Childhood Education, Inclusive Learning Environments, Montessori Architecture, Universal Design

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INTRODUCTION

Addressing the global challenges of disability access and educational inequity requires a systematic re-evaluation of how early-childhood learning environments are conceived, designed, and organized. Traditional educational settings often locate learning difficulties within students rather than recognizing barriers embedded in curricula and physical environments (Ewe & Galvin, 2023; Bertling et al., n.d.). Universal Design for Learning (UDL) draws on the broader concept of Universal Design (UD) and applies inclusive-design principles to curriculum and instruction. It is a research-based framework that seeks to optimize learning by anticipating learner variability from the outset (Ewe & Galvin, 2023). UDL aims to reduce curricular barriers by creating equitable access and meaningful participation for diverse learners in early childhood settings (Bertling et al., n.d.; Rosati, 2021). Maria Montessori emphasized the pedagogical role of the physical environment in children's learning and development (Casha, 2015). according to longest-running alternative pedagogy globally since 1907. The Montessori prepared environment is intentionally organized to support children's independence, autonomy, and self-directed activity (Casha, 2015). Key features of Montessori include child-centered scaling of furniture and fixtures, freedom of movement, and self-correcting materials, which are structurally aligned with selected principles of UD (Rosati, 2021). Actually, the purposes of UD that concentrate on creating proper solution for all the necessities have been aspired from Montessori's design philosophy for an environment that fits the needs of all children (Rosati, 2021). In addition, in addition, a recent national randomized controlled trial (RCT) reported higher scores in reading, executive function, short-term memory, and theory of mind by the end of kindergarten among children attending public Montessori preschool (Lillard et al., 2025). Despite this clear theoretical synergy and demonstrated efficacy, a critical Montessori architectural gap persists. Researches on the cases of the Montessori facilities assume that there may be inadequateness and material deficiencies in Montessori-such as rigid forms, walled separations, or insufficient use of space that directly reduce the quality of education delivered (Khan & Ebrahimi, 2021).

Consequently, a major research gap is the lack of a formal, integrated model systematically merging high Montessori pedagogical fidelity with rigorous UD/UDL mandates (Ewe & Galvin, 2023). The mentioned gap has been worsening by the critical lack of empirical research concerning UDL implementation in preschool and early years' education (Ewe & Galvin, 2023). This is used to prevent the designers from determining the optimal level of architectural fidelity required to maximize positive student outcomes (Lillard et al., 2025).

Therefore, this study is designed and created to empower develop the Universal Montessori Kindergarten Design Framework (UMKDF), presented here as a novel, systematic contribution. The UMKDF is to create measurable design outputs and operational checklists to alter the Montessori basics into global accessible architecture. There are different criteria that Composes the framework's concentration, such as kinetic and flexible zoning. Low furniture partitions, anthropometric detailing of all fixed elements and material strategies are used by this zoning that are used to enhance perceptible information (Casha, 2015; Hashimoto et al., 2025). Effectiveness and being highly cost-effective are from main features of UMKDF that intentionally accommodates higher child-to-teacher ratios (25+ children per class), which more than compensates for material costs and leads to substantial operational savings (Lillard et al., 2025).

This dual justification (educational efficacy and economic responsibility) validates the architectural optimization proposed. The theoretical foundations,

detailing the conceptual agreements and conflicts between Montessori and UD are detailed in the following. Consequently, it constructs the UMKDF which defines specific design outputs and necessary risk-control layers for the prevention of failures. The analysis concludes with a retrospective analytical assessment of the proposed framework, identifying critical assumption, research gaps and policy- level implications for inclusive educational architecture.

Accordingly, the aim of this study is to develop and analytically examine an architectural framework that systematically translates Montessori pedagogical principles and Universal Design requirements into spatial, dimensional, sensory, accessibility, and risk-control criteria for kindergarten environments. The study specifically seeks to: (1) identify the principal architectural correspondences and conflicts between Montessori pedagogy and Universal Design; (2) translate these principles into an integrated set of spatial organization, circulation, anthropometric, sensory, and risk-management requirements; and (3) retrospectively examine the analytical applicability of the proposed UMKDF through documented kindergarten case studies. The study is guided by the following research question: How can Montessori pedagogical principles and the seven Principles of Universal Design be systematically translated into an architectural framework that supports inclusive spatial organization, child autonomy, accessibility, sensory regulation, and safe use in kindergarten environments?

LITERATURE REVIEW

Montessori Pedagogy as the Foundation

Commitment to a structured set of spatial principles is the most important feature of Montessori (Casha, 2015). Prepared environment is the most critical foundational principle which is established by Maria Montessori as first proponent of a pedagogical physical environment (Casha, 2015). This meticulously managed structure is designed to support the child's physical and psychological development (Li & Zhao, 2023), transmitting values of self-activity and responsibility (Casha, 2015). The physical structure empowers an environment of a powerful order, often encapsulated by the motto: "everything in its place and a place for everything" (Rosati, 2021). Autonomy and independence is the principle of the prepared environment, which is foundational to the pedagogy (Hashimoto et al., 2025). A powerful learning environment that enables children to learn via free choice, discovery, hands on material and self-assessment must be encouraged and persuaded by self-directed activity. The mentioned activity is implemented without constant adult-intervention. (Lillard et al., 2025; Casha, 2015). The pedagogy of Montessori strongly relies on Sensorial Learning. This pedagogy oof multi-sensory eases the essential cognitive acquisition of abstract concepts (Utami & Ishartiwi, 2025; Rosati, 2021). Self-correcting is the core of these moralizing and didactic materials that allow children to understand their mistakes instantly, reduce the need for teacher intervention, and nurture autonomy and resilience (Casha, 2015).

The Child-Centered Scaling is the foundational principle of architectural design (Pang et al., 2024). The facilities must be physically set with the needs of the children's small scale to indicate that the space is created for them (Casha, 2015). These adaptations aren't done but by lowering window sills, handrails, and sinks, while furniture must be light and movable so children can rearrange the space without assistance, reinforcing functional independence (Casha, 2015; Pang et al., 2024).

The Inclusion Framework: Universal Design and Universal Design for Learning (UDL)

The UDL provides an inclusive early childhood environment; it ensures an equitable access and effective attendance by flexible and creative approaches within a developmentally appropriate setting (Bertling et al., n.d.). Architectural translation of UD often involves incorporating features such as varied ramps and chutes to allow access whether children are standing or seated, supporting the principle of Equitable Use (Bertling et al., n.d.). The ability of the Montessori Method to offer multi-sensory materials directly supports the UDL principle of Multiple Means of Representation (Rosati, 2021). In addition, it's optional to select materials at a single pace that aligns with UDL's concentration on Engagement, fostering determination and persistence (Rosati, 2021).

In the present study, inclusivity is interpreted more broadly than physical accessibility or anthropometric scaling alone. Within the combined UD/UDL perspective, learner variability is considered across four interrelated domains: physical and mobility needs, sensory and perceptual needs, cognitive and learning variability, and emotional/self-regulatory needs. Physical and mobility inclusion requires barrier-free circulation, low physical effort, and child-scaled access to furniture and fixtures. Sensory and perceptual inclusion requires control of excessive acoustic stimulation together with clear, multi-sensory environmental information. Cognitive and learning inclusion requires flexible environments that support different modes of engagement and representation, while emotional and self-regulatory inclusion requires opportunities for both active communal participation and quieter retreat or individual concentration. These dimensions extend the framework beyond conventional accessibility and position inclusion as a multidimensional environmental requirement (Bertling et al., n.d.; Rosati,2021; Casha, 2015).

For terminological consistency, this study adopts the seven Principles of Universal Design (Version 2.0) established by the Center for Universal Design: (1) Equitable Use, (2) Flexibility in Use, (3) Simple and Intuitive Use, (4) Perceptible Information, (5) Tolerance for Error, (6) Low Physical Effort, and (7) Size and Space for Approach and Use (Center for Universal Design, 1997). These principles address the usability of products and environments for people with diverse abilities and are used in the UMKDF as the formal architectural accessibility reference. Universal Design for Learning (UDL), in contrast, is retained as a complementary pedagogical framework addressing learner variability through multiple means of engagement, representation, and action/expression.

Theoretical Synergies and Conflicts

Montessori's design for a perfect environment for all children stands for the efficient credit, (Rosati, 2021). The convergence shows how Montessori prepared the environment that fits the UDL goals. (Rosati, 2021). For example, the commitment of Montessori to the manageable furniture by children based on size and weight satisfies the UD fundamentals of decreased physical effort and size and space for Approach and Use, though decreasing frustration and functional barriers caused by adult-sized settings. (Rosati, 2021). The environment which is governed by the rule "everything in its place and a place for everything" fits the principle of UD. (Rosati, 2021).

In addition, the pedagogical alignment is strong: Montessori's multisensory, concrete, and self-correcting materials support the UDL principle of Multiple Means of Representation by engaging visual, tactile, and auditory sensory modalities simultaneously to introduce concepts (Rosati, 2021). The emphasis on free choice, repetition, and self-correction supports the UDL principle of Multiple

Means of Engagement, fostering persistence, self-regulation, and resilience (Rosati, 2021). A significant tension nevertheless exists between Montessori's open-plan layouts and UDL-informed requirements for clear environmental cues and sensory management. Montessori provides the open-plan continuous spatial layouts for promoting unconstrained motion and community interactions. (Hashimoto et al., 2025; Jojy & Prakash, 2025). Freedom of movement is guaranteed in this way (Rosati, 2021), but due to varying activity schedules in open environments, noise stress affects the concentration of specialized works (Meuser, 2019; Victoryana et al., 2024). On the other hand, there is a physical environment need for UDL to accommodate the needs of diverse sensory input and management (Bertling et al., n.d.). Architectural solutions are needed when these conflicts come to initiation to achieve polyvalence the capacity for a space to support highly structured, focused individual work alongside fluid group exploration—often through methods beyond fixed walls, such as flexible partitions (Pang et al., 2024).

The Critical Research Gap

It is indicated by the literature that the Montessori Method is very effective, which provides positive outcomes in cognitive and executive function (Lillard et al., 2025). Although the foundations of UD are theoretically aligned with Montessori's prepared environment (Rosati, 2021), a critical knowledge gap prevents systematic, high-fidelity integration. A critical lack of empirical research exists concerning UDL implementation in preschool and early years education across systematic reviews of European school settings (Ewe & Galvin, 2023).

In addition, research of UDL focuses on qualitative metrics like perception of engagement more than measuring objective learning outcomes or achievement (Ewe & Galvin, 2023).

Empirical validations miss regarding specific architectural elements such as the optimal geometry of flexible partitioning or the precise sensory management required for neurodiverse learners as indicated by the methodological gaps. Importantly, the data that connects variation in architectural implementation fidelity to student outcomes is not yet fully available to researchers that makes the procedure difficult to determine the level of fidelity required in the built environment (Lillard et al., 2025). This research proposes that the Universal Montessori Kindergarten Design Framework provides rigorous, measurable criteria that integrate Montessori pedagogical fidelity with UD/UDL architectural mandates, thereby bridging this critical gap.

METHODOLOGY

The development of the Universal Montessori Kindergarten Design Framework (UMKDF) followed a qualitative framework-development methodology designed to synthesize educational theory with evidence-based architectural knowledge. The study was based exclusively on secondary evidence and consisted of three stages: systematic literature review, secondary comparative analysis of established architectural case studies, and design framework synthesis. No primary data were collected from Montessori educators, architects, inclusive education specialists, children, or other users. Accordingly, the purpose of the present study was to develop and analytically examine the proposed framework rather than to provide empirical stakeholder validation. Figure 1 summarizes the progression from theoretical inputs to comparative analysis and framework synthesis.

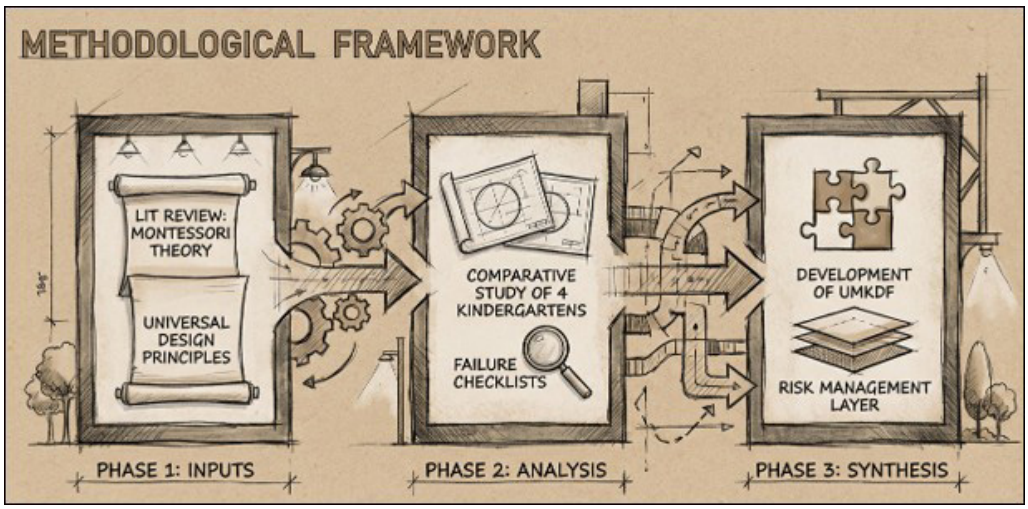


Figure 1. The methodological framework illustrating the progression from theoretical synthesis to the development of the UMKDF
Source: Produced by the authors with generative AI assistance; reviewed and edited by the authors.

Research Methodology

Systematic Literature Review

A comprehensive review of foundational pedagogy is included in the first stage which synthesizes the theories to extract the core principles that serve as the theoretical "inputs" for the UMKDF (Rosati, 2021). Three primary theoretical pillars are focused in thsis review. Firstly, the definitions of the Prepared Environment Autonomy, Sensorial Learning, and Child-Centered Scaling stand as the main principles of Montessori Pedagogy that are extracted. (Casha, 2015). These principles establish the pedagogical requirements for spatial function, such as the need for lightweight, movable furniture and unconstrained movement (Casha, 2015). Secondly, the architectural principles of Universal Design (UD) and the pedagogical framework of Universal Design for Learning (UDL) were analysed (Rosati, 2021). The architectural accessibility requirements were formalized against all seven Principles of Universal Design: Equitable Use, Flexibility in Use, Simple and Intuitive Use, Perceptible Information, Tolerance for Error, Low Physical Effort, and Size and Space for Approach and Use (Center for Universal Design, 1997). The principles of UDL documents a proactive approach to ensure equitable access and meaningful participation for diverse learners (Bertling et al., n.d.)

Secondary Comparative Analysis of Established Case Studies

In the second stage, four existing kindergarten case studies were examined to identify successful design patterns and practical failure scenarios: Fuji Kindergarten (Japan), My Montessori Garden Preschool (Vietnam), Ihsan Doğramacı Montessori Kindergarten (Turkey), and DPS Kindergarten (India) (Hashimoto et al., 2025; Pang et al., 2024; Khan & Ebrahimi, 2021; Jojy & Prakash, 2025). Circular, open-plan layouts, flexible partitions, and seamless indoor-outdoor continuity were included in successful patterns (Hashimoto et al., 2025; Pang et al., 2024). Importantly, the case-study source highlighted the importance of locating the kitchen and dining areas adjacent to one another as a functional planning consideration (Khan & Ebrahimi, 2021). This analysis yielded essential architectural data and a checklist of failure prevention requirements.

Framework Synthesis

The final stage contained synthesis of the theoretical principles was built in stage 1 with the pragmatic design lessons and failure checklists extracted in Stage 2. Mapping the main Montessori spatial needs (e.g., freedom of movement) was involved in this synthesis to corresponding UD principles (e.g., Equitable Use) to define specific architectural criteria (Rosati, 2021). The outcome of this phase is the Universal Montessori Kindergarten Design Framework (UMKDF), which

integrates pedagogical inputs, spatial transformation mechanisms, defined design outputs, and necessary risk-control layers to ensure both educational fidelity and universal accessibility (Casha, 2015; Bertling et al., n.d.).

Study Scope and Validation Boundary

The present study is limited to conceptual framework development based on secondary evidence. The literature synthesis and comparative case study analysis provide an analytical foundation for developing the UMKDF, but they do not constitute empirical validation by stakeholders or end users. Consequently, the framework's practical usability, stakeholder acceptability, and contextual adaptability remain to be empirically examined. Future studies should validate the UMKDF through semi-structured interviews or focus-group discussions with Montessori educators, architects specializing in child-centered environments, and inclusive education specialists, followed where possible by post-occupancy evaluation in operational kindergarten settings. Such future POE should incorporate measurable environmental, behavioural, safety, accessibility, and educational indicators to test whether greater fidelity to UMKDF principles is associated with improved real-world outcomes.

Retrospective Scoring Procedure and Operational Rubric

To reduce interpretive subjectivity, the retrospective scoring system was operationalized as an evidence-constrained ordinal rubric based on predefined and observable architectural indicators documented in the cited case-study sources. A score of 0 indicates documented non-compliance or a documented failure condition; a score of 1 indicates partial, mixed, indirect, or insufficiently documented compliance; and a score of 2 indicates clearly documented compliance supported by explicit architectural features or measured performance where such data are available. Criterion-specific rules were defined as follows. Spatial flexibility: 0 = predominantly fixed or cellular/ walled configuration with no documented adaptability; 1 = mixed fixed and flexible spatial configuration; 2 = predominantly open or modular configuration with documented movable elements, flexible zoning, or continuous circulation. Anthropometric responsiveness: 0 = no documented child-scaled adaptation; 1 = partial or selective child-scaling; 2 = consistent documented evidence of child-scaled furniture, fixtures, or access elements.

Acoustic risk control: 0 = documented noise-related problems without documented mitigation; 1 = partial or indirect control, or insufficiently documented acoustic performance; 2 = explicit evidence of an engineered acoustic-control strategy and/or measured acoustic performance consistent with recognized reverberation-time, speech-intelligibility, or sound-absorption criteria.

Sightline performance: 0 = documented obstruction of visual supervision; 1 = partial, mixed, or insufficiently documented sightline performance; 2 = explicit evidence of clear visual supervision through low or transparent partitions or an unobstructed layout. Absence of a reported problem was not treated as evidence of full compliance, and where evidence was incomplete or ambiguous, a score of 2 was not assigned. The rubric therefore standardizes the interpretation of secondary evidence but does not replace direct physical measurement or independent expert assessment.

The Universal Montessori Kindergarten Design Framework

The methodology described above produced the Universal Montessori Kindergarten Design Framework (UMKDF) as a systemic tool for translating integrated educational and accessibility principles into reproducible

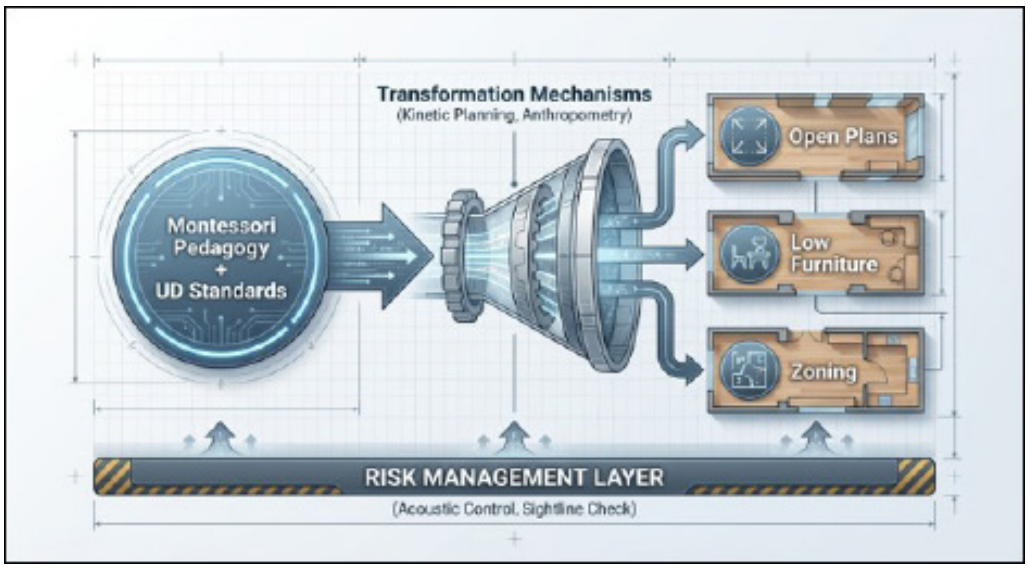


Figure 2. The Universal Montessori Kindergarten Design Framework (UMKDF) system architecture diagram. This visual schema details how abstract pedagogical and accessibility inputs are filtered through architectural transformation mechanisms to produce. Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

architectural design (Rosati, 2021). The UMKDF is structured into a logical, four stage process which guarantees that abstract theory is converted into concrete and evaluable design outputs in a systematic way. Figure 2 illustrates the systematic architecture of the UMKDF, demonstrating the flow from theoretical inputs through transformation mechanisms to verifiable outputs, all underpinned by a protective risk-control layer.

Inputs (Pedagogical & Accessibility)

This basic and important layer consist of the main integrated foundations which is taken from the systematic review. All the pedagogical inputs are the basic tenets of Montessori, emphasizing the Prepared Environment, Autonomy, and Sensorial Learning (Casha, 2015; Rosati, 2021). The architectural accessibility inputs are aligned with the seven Principles of Universal Design Equitable Use, Flexibility in Use, Simple and Intuitive Use, Perceptible Information, Tolerance for Error, Low Physical Effort, and Size and Space for Approach and Use—while UDL provides the complementary pedagogical dimensions of engagement, representation, and action/expression (Center for Universal Design, 1997; Rosati, 2021). As an example, the Montessori need for lightweight, movable furniture aligns directly with the UD principle of Low Physical Effort, forming a single requirement for accessible, child-sized furnishings (Rosati, 2021). Similarly, the commitment of Montessori to multi-sensory materials supports the UDL principle of Multiple Means of Representation (Rosati, 2021; Utami & Ishartiwi, 2025).

Spatial Transformation Mechanisms

These strategies translate abstract theoretical inputs into concrete design actions, focusing on the way in which spaces are modified to support pedagogical goals and universal access (Casha, 2015). The main mechanisms include anthropometric detailing, which requires all fixed and movable elements to be dimensioned according to children's anthropometric measurements, thereby promoting independent use (Casha, 2015; Pang et al., 2024). The next mechanism is the implementation of Kinetic and Non-Linear Planning, preparing open-plan layouts and flexible partitions (e.g., low-height shelving) to define polyvalent zones and enhancing Freedom of Movement (Hashimoto et al., 2025; Pang et al., 2024). In addition, this phase contains Material and System Honesty that uses natural and authentic materials (wood, glass) and potentially exposing structural or operational systems (e.g., pipework) that are used to transform the building into a didactic, multi-sensory resource (Casha, 2015).

Design Outputs

This phase composes the tangible architectural results that are taken from the transformation mechanisms that provide measurable and verifiable metrics for construction and design review. The plans that are included in these outputs must illustrate open-plan, non-rigid layouts, often in circular or irregular forms (Hashimoto et al., 2025). The sections must indicate the Anthropometric Detailing which requires lowered window sills, and comply with minimum ceiling height requirements of at least 2.5 m (Casha, 2015; Meuser, 2019). The use of flexible partitioning and the inclusion of specialized areas and areas for quiet retreat and individual introspection are defined by the zoning outputs. (Li & Zhao, 2023; Casha, 2015). It must be ensured that the circulation patterns must be clear, continuous, and integrated with Motor Affordances (e.g., ramps, multi-level platforms) (Hashimoto et al., 2025; Carrasco, 2025). Finally, Furniture output requires elements that are lightweight, movable, and scaled (e.g., stool heights from 130 mm to 360 mm) (Casha, 2015; Meuser, 2019).

Risk-Control Layers

The last component of the UMKDF stands as a confirmation step, which consists of engineered measures to mitigate predictable failures identified in case studies (Khan & Ebrahimi, 2021). These controls ensure that the pursuit of open architecture does not compromise safety or pedagogical effectiveness. Acoustic Engineering Control is the core part of the main layers that mandate the proactive use of sound-absorbing materials used to reduce the risk of noise stress in open settings that affects concentration (Li & Zhao, 2023; Meuser, 2019). For design-stage verification, the acoustic-control layer should be checked against measurable reverberation-time, speech-intelligibility, and material-absorption criteria, as detailed in Section 5.4 and Table 3. Low-weight furniture and transparent construction are required for the sightline integrity check to ensure continuous supervision and prevent obstructed views (Jojy & Prakash, 2025). Operational risks are managed through the Facility Adjacency Check, which verifies that complementary areas (e.g., kitchen and dining) are located adjacent to each other, thereby avoiding workflow deficiencies (Khan & Ebrahimi, 2021). Finally, the Accessibility Surface Check prohibits uneven paving in outdoor areas, ensuring Equitable Use for all children (Casha, 2015).

CASE STUDY ANALYSIS

Study Analysis: Integrating Montessori and Universal Design in Kindergarten Architecture. This analysis examines Kindergarten case studies against the main requirements of Montessori pedagogy and Universal Design (UD) principles to systematically extract measurable design lessons and recognize critical failure patterns.

Moving from theory to practice, landmark case studies reveal successful design patterns and practical failures in the integration of Montessori and inclusive architecture. In successful models, the built environment is re-conceptualized as an active, multi-sensory "third teacher" (Carrasco, 2025).

Successful design patterns: Kinetic and non-linear planning are consistently indicated in Effective design, which is seen in Fuji Kindergarten's circular, open-plan layout and continuous roof playground that directly supports unconstrained motion and cognitive development (Hashimoto et al., 2025). Using low-weight, movable furniture and shelving as flexible separators were achieved by the removal of rigid, hierarchical boundaries that are used instead of walls that empowers autonomy and adaptable zoning (Pang et al., 2024; Jojy & Prakash, 2025). Furthermore, the commitment to seamless outdoor-indoor transition which was facilitated by large glass facades and gliding doors (Hashimoto et

al., 2025), evolves Sensorial Learning by providing continuous visual and physical connection to nature, which is extremely critical for stress reduction and exploration (Jojy & Prakash, 2025). Leveraging verticality is included in the next successful patterns by multi-level platforms (Carrasco, 2025) and utilizes natural and objective materials (e.g., wood, bamboo) to enrich the sensory experience (Two et al., 2023).

Practical challenges and failures: Practical implementation usually introduces vital challenges despite of philosophical alignment. Aural stress stands as a remarkable risk in opem-plan or dynamic environments like Fuji Kindergarten, where high background noise levels can disrupt concentration (Meuser, 2019; Victoryana et al., 2024). In addition, custom designs like DPS Kindergarten, which are known by rigid structure and walled separations, limits the Freedom of Movement and create obstructed view that leads to supervision failures and restricted interaction (Jojy & Prakash, 2025). The analysis of Ihsan Doğramacı Montessori Kindergarten indicates that, although the school seeks to apply Montessori principles, deficiencies in the existing architecture and materials affect the quality of the educational environment. The source also reports insufficient use of indoor and outdoor spaces and emphasizes the importance of locating the dining room and kitchen side by side (Khan & Ebrahimi, 2021). In the present study, these reported deficiencies are interpreted as potential limitations related to the UD principle of Equitable Use (Center for Universal Design, 1997; Khan & Ebrahimi, 2021).

Part 2: Comparative Synthesis Matrix

To enable a structured and objective comparison, a comparative synthesis matrix is constructed based on the core evaluation criteria derived from the UMKDF framework. A scoring-based assessment selected case studies across key dimensions is presented in the table which includes spatial flexibility, anthropometric responsiveness, and risk management performance. Table 1 presents the Comparative synthesis matrix of the selected kindergarten case studies based on Montessori compliance, Universal Design compliance, Spatial flexibility, key strengths and major failure risks.

THE UNIVERSAL MONTESSORI KINDERGARTEN DESIGN FRAMEWORK (UMKDF)

The development of the Universal Montessori Kindergarten Design Framework (UMKDF) followed a wonderful qualitative research process designed to synthesize foundational educational theory with evidence-based architectural practice based on three-stages.This methodology provides a renewable design process which is essential to address the current research flaw concerning the systematic application of inclusive design foundations within early childhood education environments (Ewe & Galvin, 2023). The UMKDF is structured into four-stage process which ensures that abstract theory is systematically converted into concrete, evaluable design outputs.

Framework Inputs (Pedagogical & Accessibility)

The initial phase consisted of a Systematic Literature Review to establish the theoretical "inputs" for the UMKDF (Rosati, 2021). This included extracting the main spatial foundations of Montessori Pedagogy, which explains the Prepared Environment (Casha, 2015; Rosati, 2021), Autonomy and Independence (Casha, 2015; Hashimoto et al., 2025), Freedom of Movement (Rosati, 2021), and Child-Centered Scaling (Pang et al., 2024; Casha, 2015). Also, the framework formalized accessibility which is taken from Universal Design (UD) and Universal Design for Learning (UDL) that shows us to understand that the UD is directly inspired by Montessori's design philosophy (Rosati, 2021). The architectural

Feature	Fuji Kindergarten (Japan)	My Montessori Garden Preschool (Vietnam)	Ihsan Doğramacı Montessori Kindergarten (Turkey)	DPS Kindergarten (India)
Montessori Compliance	High (Oval form, autonomy, free movement) (Hashimoto et al., 2025)	High (Open-plan, child-scaled furniture, flexible zoning) (Pang et al., 2024)	Montessori model adopted; principles reportedly applied as far as possible, although architectural and material deficiencies remain (Khan & Ebrahimi, 2021)	Low (Rigid structure, walled separation restricts movement) (Jojy & Prakash, 2025)
UD Compliance	High (Scale, equitable access, visual transparency) (Hashimoto et al., 2025; Rosati, 2021)	High (Anthropometric scale, Low Physical Effort via movable furniture) (Pang et al., 2024)	Limited (Reported architectural and material deficiencies may constrain inclusive use; UD-specific compliance was not directly assessed) (Khan & Ebrahimi, 2021)	Low (Obstructed views, limited movement, rigidity) (Jojy & Prakash, 2025)
Spatial Flexibility	Very High (Open-plan, movable partitions, continuous roof play) (Hashimoto et al., 2025; Pang et al., 2024)	High (Open-plan with flexible separators) (Pang et al., 2024)	Insufficiently documented (underuse of indoor and outdoor spaces is reported, but spatial adaptability is not directly assessed) (Khan & Ebrahimi, 2021).	Low (Rigid structure, walled separations) (Jojy & Prakash, 2025)
Key Strength	Seamless indoor-outdoor flow via gliding doors and nature integration (Hashimoto et al., 2025)	Use of low-height, movable furniture as highly flexible separators (Pang et al., 2024)	Montessori principles are reportedly applied as far as possible; classroom materials are arranged within children's reach (Khan & Ebrahimi, 2021).	May mitigate general background noise better due to compartmentalization (Meuser, 2019)
Key Failure/ Risk	Potential for noise stress and disruption due to maximum openness (Victoryana et al., 2024)	Risk of noise stress due to open structure; lack of documented acoustic strategy (Meuser, 2019)	Insufficient use of indoor and outdoor spaces; inadequate interior facilities and materials; need for appropriate adjacency between kitchen and dining areas. (Khan & Ebrahimi, 2021)	Obstructed views leading to supervision failures; under-stimulation (Jojy & Prakash, 2025)

Note: Qualitative classifications represent the authors' analytical synthesis of the cited case-study evidence and are not ratings reported by the original sources.

Table 1. Comparative synthesis matrix of selected kindergarten case studies.
Source: authors' synthesis based on the cited literature.

accessibility inputs are structured against all seven Principles of Universal Design, while UDL contributes complementary pedagogical requirements related to multiple means of engagement, representation, and action/expression. The direct correspondence between these principles and the UMKDF architectural requirements is presented in Table 2. To broaden the inclusivity scope of the UMKDF, the accessibility inputs are organized into four user-need domains. First, physical and mobility need address barrier-free movement, reach, child-scaled access, and low physical effort. Second, sensory and perceptual need address acoustic comfort, multi-sensory information, environmental legibility, and the reduction of sensory overload. Third, cognitive and learning need address learner variability through flexible spatial configurations and multiple opportunities for engagement and representation. Fourth, emotional and self-regulatory needs address the availability of quiet retreat spaces, opportunities for focused individual activity, and controlled transitions between high- and

Table 2. Direct mapping of UMKDF inputs to the Seven Principles of Universal Design

Official Universal Design Principle	Corresponding UMKDF Input / Requirement	Architectural Translation within UMKDF
1. Equitable Use	Inclusive access; physical/mobility needs	Barrier-free circulation, accessible surfaces, equivalent access to indoor and outdoor learning areas
2. Flexibility in Use	Autonomy; freedom of movement; learner variability	Flexible zoning, movable furniture, adaptable activity areas, multiple spatial configurations
3. Simple and Intuitive Use	Prepared Environment; cognitive/ spatial legibility	Clear spatial organization, predictable zoning, consistent placement of learning materials, reduced unnecessary complexity
4. Perceptible Information	Sensorial Learning; sensory/ perceptual needs	Multi-sensory environmental cues, visual transparency, legible spatial information, complementary visual/tactile/auditory information
5. Tolerance for Error	Safety and risk-control requirements	Safe circulation, hazard reduction, supervision sightlines, protective elements, and risk-management checks
6. Low Physical Effort	Child-centered scaling; physical/ mobility needs	Lightweight movable furniture, lowered fixtures, accessible storage, reduced operating/reaching effort
7. Size and Space for Approach and Use	Anthropometric responsiveness; barrier-free access	Child-scaled dimensions, adequate approach and reach space, unobstructed circulation, accessible fixtures and activity zones

Source: Authors' synthesis based on Center for Universal Design (1997), Rosati (2021), Casha (2015), Bertling et al. (n.d.), and Pang et al. (2024).
Note: The seven UD principles provide the formal architectural accessibility structure of the UMKDF, while UDL functions as a complementary pedagogical framework addressing learner variability.

low-stimulation zones. These domains function as cross-cutting accessibility inputs within the UMKDF rather than as separate design systems.

Spatial Translation Mechanisms

The UMKDF integrates Spatial Transformation Mechanisms to change integrated theoretical inputs into rule-based, concrete design actions (Pang et al., 2024). Kinetic and Non-Linear Planning: The mix of Freedom of Movement (Montessori) and Flexibility in Use (UD) is meant into mandates for open-plan layouts used for non-rigid, continuous spatial configurations, often circular or irregular, to promote fluid exploration (Hashimoto et al., 2025; Jojy & Prakash, 2025). Zoning relies on flexible partitions, like low furniture or shelving, to define polyvalent activity zones while maintaining visual transparency (Pang et al., 2024).
Figure 3, illustrates the spatial shift from a rigid/ static classroom layout to the proposed UMKDF kinetic/ polyvalent plan, where flexible zoning, movable furniture and open circulation support freedom of movement and adaptive learning.

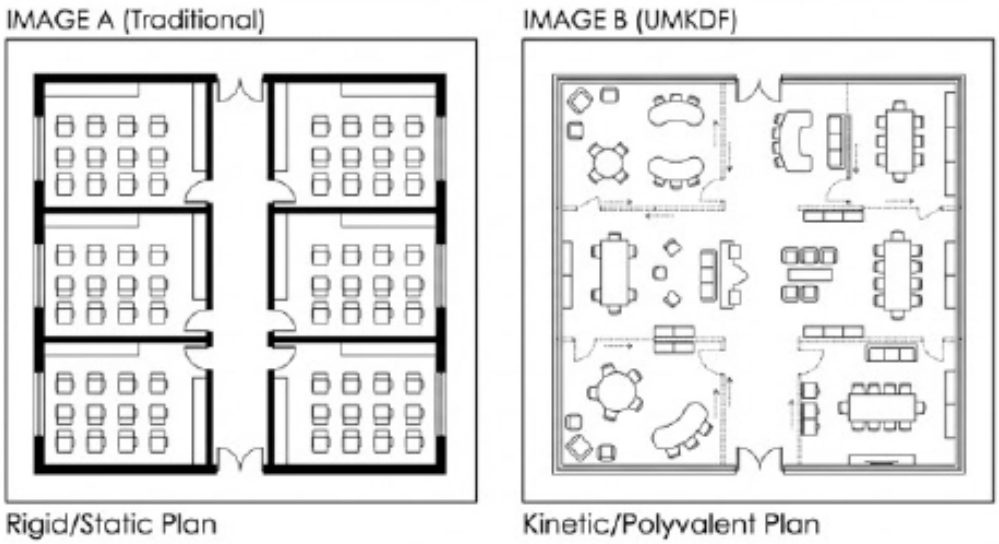


Figure 3. Comparative spatial analysis schema. (Left) A traditional 'Rigid/Static Plan' characterized by thick-walled cellular classrooms and fixed furniture, limiting movement and flexibility. (Right) The proposed UMKDF 'Kinetic/Polyvalent Plan' utilizing flexible zoning, movable furniture and continious ciculation.

Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

Anthropometric Detailing: The input for Child-Centered Scaling (Montessori) and Low Physical Effort (UD) needs all accurate elements such as sinks, and window sills that should be anthropometrically lowered to the child's size, which empowers self –reliance and unassisted function (Casha, 2015). It's important to consider that all the materials and staffs must be lightweight and easy for children to handle independently. (Rosati, 2021; Pang et al., 2024). Material and System Honesty: Sensorial Learning (Montessori) and Perceptible Information (UD) prioritize natural, objective, and non-toxic materials (wood, bamboo, glass) to enrich the multisensory experience (Two et al., 2023). This mechanism further mandates that structural or operational systems (e.g., pipework) be exposed to function as didactic sensory resources (Casha, 2015).

Design Control System (Design Outputs)

The Design Control System describes the quantifiable architectural outputs resulting from the translation mechanisms, establishing verifiable metrics for the final design and construction.

Plans and Zoning: Open-plan environments must be specified in the design outputs which integrate functional activity rooms required for scientific exploration alongside larger activity areas. (Li & Zhao, 2023). Zoning implies flexible partitioning to maintain continuity while integrating areas for quiet retreat and individual introspection (Casha, 2015).

Sections and Scale: The drawings from each section should verify Anthropometric Detailing across all fixtures (Casha, 2015) and confirm compliance with minimum ceiling heights of at least 2.5 m (Meuser, 2019). Some elements like play stools are needed for the furniture to conform to defined anthropometric ranges, starting at 130 mm (Meuser, 2019). Figure 4 shows the precise application of these anthropometric standards illustrating the relationship between the child's stature, reach radius and furniture height.

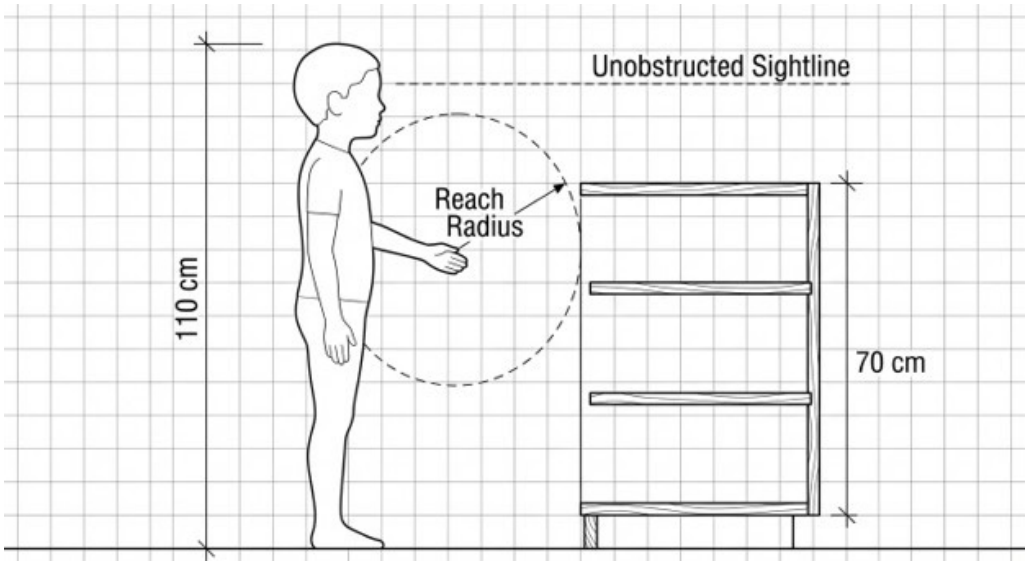


Figure 4. Anthropometric section detailing the 'Child-Centered Scaling' design output. The diagram illustrates a 5-year-old child (110 cm stature) interacting with a low-height shelving unit (70 cm). The 'Reach Radius' affirms unassisted access to materials. It validates the anthropometric calibration of spatial elements and reinforces independence, autonomy, and self-directed activity as core principles of the Montessori learning environment.

Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

Circulation: Circulation output mandates clear, continuous, and unobstructed paths to maximize Freedom of Movement (Rosati, 2021). Pathways must be multifunctional and should integrate motor affordances like ramps and multi-level platforms to stimulate physical exploration (Hashimoto et al., 2025; Carrasco, 2025). A seamless transition is mandated using large gliding doors or glass facades to ensure visual connectivity with nature (Hashimoto et al., 2025; Jojy & Prakash, 2025).

Risk Management Layer

The last and final component of the UMKDF works as a certification and safety system that implements engineered measures to mitigate predictable failures thus ensuring UD compliance and functional adequacy.

Mitigation of Sensory Overload (Acoustic Stress): The acoustic-control layer of the UMKDF should be specified through measurable performance criteria rather than through generic recommendations for "sound-absorbing materials." As an external design benchmark, nursery school rooms should target a mid-frequency reverberation time (Tmf) of ≤ 0.6 s, while open-plan teaching areas should target Tmf ≤ 0.5 s (Department for Education, 2015). For open-plan learning environments, speech intelligibility should also be considered; Building Bulletin 93 specifies a Speech Transmission Index (STI) of ≥ 0.61 within an instructional group and ≤ 0.30 between simultaneously operating groups (Department for Education, 2015). Architecturally, acoustic control should prioritize a continuous sound-absorbing ceiling, supplemented where necessary by absorptive wall panels, ceiling baffles, or other tested absorbers. As a practical specification benchmark, ceiling and wall absorbers with a Noise Reduction Coefficient (NRC) of approximately 0.70 or higher can provide high sound absorption, while rooms with ceilings above approximately 3 m may require additional wall treatment to achieve the required reverberation-time target (Alberta Infrastructure, 2026). Low-height furniture partitions used to preserve Montessori flexibility should incorporate tested sound-absorbing surfaces where they are intended to provide acoustic separation, while remaining low enough to preserve adult supervision sightlines. No fixed room-volume ratio is prescribed in the UMKDF because the required amount and placement of absorption depend on room geometry, occupancy, surface finishes, and activity patterns. Final acoustic performance should therefore be verified through room-acoustic modelling and, where possible, post-occupancy measurement rather than inferred from the presence of acoustic materials alone. Table 3 summarizes the acoustic performance benchmarks and corresponding architectural responses proposed for UMKDF learning spaces.

Mitigation of Sensory, Perceptual, and Cognitive Exclusion: The UMKDF extends risk management beyond physical accessibility by considering children who may experience sensory overload, perceptual difficulty, or different cognitive

Table 3. Acoustic performance benchmarks and architectural responses for UMKDF learning spaces

Acoustic parameter	Proposed UMKDF design benchmark	Architectural response
Nursery learning-space reverberation time	Tmf ≤ 0.6 s	Sound-absorbing ceiling; wall absorption where required
Open-plan teaching-area reverberation time	Tmf ≤ 0.5 s	Increased ceiling/wall absorption and acoustic zoning
Speech intelligibility within instructional group	STI ≥ 0.61	Control background noise and reverberation; orient activity zones appropriately
Speech transmission between simultaneous groups	STI ≤ 0.30	Spatial separation, absorptive screens/partitions, and activity zoning
Ceiling/wall sound absorption	NRC ≈ 0.70 or higher as a practical design benchmark	Acoustic ceiling panels, absorptive wall panels, baffles, or equivalent tested systems
High ceilings / large reflective volumes	Additional acoustic treatment required	Add wall absorbers and verify performance through acoustic modelling
Flexible Montessori partitions	Tested absorptive surfaces where acoustic separation is intended	Low-height sound-absorbing furniture partitions preserving supervision sightlines

Source: Authors' synthesis based on Department for Education (2015) and Alberta Infrastructure (2026).
Note: The values are presented as design benchmarks rather than universal regulatory requirements; applicable national/local acoustic standards should govern final project specifications.

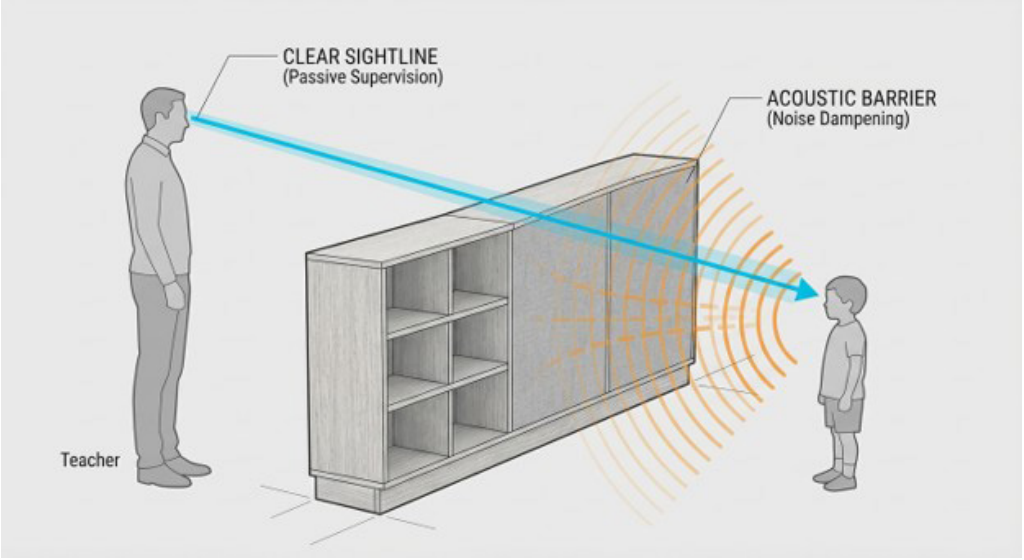


Figure 5. The Risk Management Layer mechanism. This conceptual diagram demonstrates how low-height, dual-sided furniture functions as an 'Acoustic Barrier' to mitigate noise stress between zones and as a 'Sightline Preservation Tool' that enables continuous passive supervision by teachers, thereby integrating sensory regulation with visual control in open-plan environments.

Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

and learning needs. Inclusive spatial responses include the provision of low-stimulation retreat areas, clear and consistent spatial organization, multi-sensory environmental cues, flexible activity zones, and multiple forms of engagement with learning materials. These measures are intended to reduce sensory and cognitive barriers while preserving the Montessori principles of autonomy, choice, and self-directed activity (Bertling et al., n.d.; Rosati, 2021; Casha, 2015). Mitigation of Physical Safety and Supervision Failure: All the fixtures and furniture are low-height which is ensured by the Sightline Integrity Check to maintain continuous adult supervision and prevent obstructed views (Casha, 2015; Jojy & Prakash, 2025). Furthermore, layered safety measures (e.g., nets, railings) must be integrated when utilizing structures for risk exploration (Casha, 2015). A conceptual diagram illustrating how low-height furniture simultaneously functions as an acoustic dampener and a tool for maintaining clear sightlines for passive supervision is shown in Figure 5 below.

Mitigation of Accessibility Failure: The Accessibility Surface Check don't allow the use of hazardous or uneven surfaces (e.g., uneven concrete paving) in outdoor areas, ensuring barrier-free movement and inclusive access (Casha, 2015). Physical accessibility is also fixed by providing varied ramps and chutes for children whether they are standing or seated (Bertling et al., n.d.).

Mitigation of Pedagogical/Operational Mismatch: The Facility Adjacency Check checks that related functional zones (e.g., kitchen and dining) are next to each other to prevent workflow deficiencies that undermine the Prepared Environment (Khan & Ebrahimi, 2021). This layer also requires the strategic integration of quiet spaces, such as nooks and alcoves for kids to have alone time, to balance the high stimulation of the communal, open environment (Casha, 2015).

RESULTS AND DISCUSSION
Analytical Findings (Results)
Analytical Assessment: Synergy and Compatibility

The analytical process verified a powerful theoretical alignment between main Montessori Pedagogy and Universal Design (UD) principles that validates the UMKDF's premise that the two systems are highly compatible. The compatibility Matrix has shown, the concept of UD, that concentrates on designing for all needs, inspired by Montessori's original philosophy for creating an environment that fulfils the requirements of all children. This synergy results in areas of strong compatibility where Montessori architecture inherently fulfils UD objectives.

The high degree of order required by the Prepared Environment aligns with the UD principle of Simple and Intuitive Use, which results in the development of internal psychological order in children and aids spatial understanding. The architectural mandate for accessible furniture aligns with the UD principles of Low Physical Effort and Size and Space for Approach and Use, which help remove the physical obstacles associated with adult-scaled settings. Based on the pedagogy, the multi-sensory and self-correcting materials attach directly to the UDL principles of Multiple Means of Representation and Action and Expression. Compatibility is necessary in areas such as technology integration, in which the UMKDF should adapt the approaches of UDL while respecting Montessori's fundamental preference for concrete and tangible materials.

The direct mapping presented in Table 2 demonstrates that the UMKDF is not limited to selected accessibility concepts but is terminologically aligned with all seven Principles of Universal Design. Equitable Use and Size and Space for Approach and Use are primarily reflected in barrier-free circulation and anthropometric detailing; Flexibility in Use is reflected in adaptable zoning and movable furnishings; Simple and Intuitive Use and Perceptible Information are reflected in spatial legibility and multi-sensory environmental cues; Tolerance for Error is operationalized through the Risk Management Layer; and Low Physical Effort is supported through child-scaled, lightweight, and independently usable elements.

Retrospective Analytical Application: UMKDF Scoring Matrix

Using the predefined operational rubric described in Section 3.1.5, the selected case studies were retrospectively classified across four criteria: spatial flexibility, anthropometric responsiveness, acoustic risk control, and sightline performance. The 0–2 scores were assigned from explicitly documented secondary evidence rather than from direct physical measurements or independent expert ratings. Accordingly, the matrix provides a structured comparative interpretation of the available evidence and should not be interpreted as empirical quantitative validation. Table 4 presents the resulting evidence-based classifications.

The retrospective application reveals criterion-specific performance profiles rather than a single overall ranking. Fuji Kindergarten demonstrates strong spatial flexibility and child-scaled design but also presents documented acoustic

Table 4. Comparative Retrospective Scoring of Case Studies using UMKDF Criteria. Source: Authors' synthesis based on the cited literature.

Assessment Criteria (UMKDF Layers)	Fuji Kindergarten (Japan)	My Montessori Garden (Vietnam)	Ihsan Doğramacı Montessori Kindergarten (Turkey)	DPS Kindergarten (India)
1. Spatial Inputs (Flexibility)	2 (Highly Flexible)	2 (Modular)	1 (Insufficiently documented)	0 (Rigid/Walled)
2. Anthropometry (Scale)	2 (Child-Scaled)	2 (Child-Scaled)	1 (Partial child-scaling)	1 (Standard)
3. Risk Layer: Acoustics	0 (Fail - Noise Stress)	1 (Insufficiently documented)	1 (Calm classroom atmosphere reported; no measured acoustic performance)	1 (Indirect control; no measured acoustic data)
4. Risk Layer: Sightlines	1 (Obstructed by crowds)	2 (Clear)	1 (Insufficiently documented)	0 (Blocked by walls)

Note: Scoring scale: 0 = documented non-compliance/failure; 1 = partial, mixed, indirect, or insufficiently documented compliance; 2 = clearly documented high compliance. Scores were assigned according to the operational rubric defined in Section 3.1.5 and represent ordinal classifications of secondary evidence rather than direct physical measurements or independent expert ratings.
For Ihsan Doğramacı Montessori Kindergarten, scores of 1 indicate partial or insufficiently documented evidence rather than confirmed non-compliance. The spatial-flexibility and sightline scores reflect insufficient documentation of spatial adaptability and visual-supervision performance. The anthropometric score reflects evidence that classroom materials are arranged within children's reach, although comprehensive child-scaled dimensions are not reported. The acoustic score reflects a descriptive account of a calm and quiet classroom atmosphere, without measured acoustic performance or a documented engineered acoustic-control strategy (Khan & Ebrahimi, 2021).

risk. DPS Kindergarten demonstrates limited spatial flexibility and obstructed sightlines, while its compartmentalized configuration may provide indirect acoustic separation without measured acoustic-performance evidence. My Montessori Garden demonstrates strong spatial flexibility and anthropometric responsiveness, although explicit acoustic-performance data remain insufficiently documented. Ihsan Doğramacı Montessori Kindergarten shows partial evidence of child-reachable materials and a calm classroom atmosphere; however, the available source provides insufficient documentation of spatial adaptability, measured acoustic performance, and sightline effectiveness.
These findings illustrate how the operational rubric can identify strengths, limitations, and evidence gaps across cases without treating the ordinal classifications as direct quantitative measurements.

Identified Conflicts and Research Gaps

The study of contradictions and restrictions has identified main divergence that needed systemic mitigation in the framework structure. The initial spatial contrast exists between the Montessori requirement for maximizing Freedom of Movement through open-plan layouts and the UDL need for different sensory management. The study of case issues verified that open designs like the Fuji Kindergarten holds a critical risk of noise stress because of high noise levels that are created by varying activities schedules, which disrupts the required focus for the individual work.

The tensions of the accessibility often raised from insufficient architectural execution, even in Montessori environments. Some of the failures like the irregular placement of the kitchen and the dining room created workflow flaws. In addition, design rigidities was seen in custom settings and patterns that are featured by walled separations, which led to obstructed views, resulting in useless supervision and weak connectivity to nature. The need to mandate clear and specialized functional areas like scientific discovery rooms with a flexible and non-hierarchical layout demonstrates a persistent spatial obstacle that decrees the framework's reliance on flexible partitioning.

Lastly, the analysis identified critical flaws that the UMKDF targets to fill. The most critical result of the study, taken from the Limitations Analysis, is the lack of practical research that is concerned UDL amplifications in preschool period. The existing research indicates qualitative methods that concentrates on students' and tutors' view of engagement more than thinking about the objective learning impacts or building a practical link between variations in architectural implementations fidelity and efficiency plus the quantifiable achievements of the students.

Discussion, Interpretation, and Implications
Educational and Architectural Impact

The solutions of the UMKDF integrated design is translated as mechanisms, used to formalize the architectural practice to idealize the educational results. The mandate for using child-sized, lightweight, and movable furniture reinforces the Montessori goal of nurturing autonomy and independence (Casha, 2015; Rosati, 2021). Self-activity flourishes automatically when the unassisted moving of the staffs are done by the children themselves and it decreases the reliance of them on others such as employees or tutors. (Casha, 2015; Lillard et al., 2025). According to the regulation of sensory, the framework's inclusion of Acoustic Engineering Control mitigates the spatial contrasts which were recognized in the open-plan model. (Victoryana et al., 2024). This effective measure stands against noise stress and empowers focus that makes sure that the Prepared Environment remains conducive to highly focused individual work (Li & Zhao,

2023). According to the architecture, the framework empowers an essential shift away from rigid compartmentalized classrooms toward structures that function as an active, multi-sensory "third teacher" (Carrasco, 2025). The empowerment of clear construction and low furniture (Sightline Integrity Check) ensures continuous sight lines (Jojy & Prakash, 2025), that allows non-intrusive observation and supervision essential for effective pedagogical guidance (Hashimoto et al., 2025). In addition, designing dynamic circulation systems like integrating ramps and diverse levels, influences educational performance by stimulating motor skills and maximizing exploration, which is crucial for cognitive development (Casha, 2015; Hashimoto et al., 2025).

At the architectural scale, the UMKDF operates across three interrelated levels. At the building scale, it addresses barrier-free access, indoor–outdoor continuity, and the overall relationship between learning environments and circulation systems. At the spatial-planning scale, it organizes zoning, adjacency, movement routes, sightlines, high- and low-stimulation areas, and flexible learning territories. At the architectural-detail scale, it specifies anthropometric fixtures, movable partitions, material properties, acoustic treatments, and accessible furniture. This multi-scalar structure extends the framework beyond interior furnishing decisions and positions the UMKDF as an integrated architectural design framework for inclusive kindergarten environments.

Policy Relevance

The UMKDF amounts some criteria with fully relevant criteria that is evidence-based for educational and disability inclusion policy. The framework underpins the architectural design required to sustain the cost-effective structure of public Montessori schools (Lillard et al., 2025). The model supports the practice of internationally higher child-to-teacher ratios by accommodating the high-fidelity design standards that leverages peer tutoring and the self-regulating environment. (Lillard et al., 2025). The capacity of architecture contributes directly to the model being which is estimated to 13,127$ less for a child over three years compared to traditional programs. (Lillard et al., 2025).

The UMKDF ensures UD to set the generalized principles into verifiable infrastructure mandates for inclusion policies. This requires Anthropometric Detailing (e.g., lowering sinks and handrails to child height) to promote unassisted function (Casha, 2015), and setting standards for Equitable Use, such as forbidding dangerous surfaces like uneven concrete paving (Casha, 2015). This framework is used to minimize the requirements for later expensive retrofitting by illustrating that the environment be set to create equitable access from outset (Bertling et al., n.d.), which supports systemic change across early childhood education infrastructure. (Ewe & Galvin, 2023). The framework also codifies spatial minimums, which requires a minimum of 10 square meters of outdoor space for each child to support motor coordination and natural engagement (Khan & Ebrahimi, 2021).

Limitations and Future Research

A principal methodological limitation of this study is the absence of primary empirical data. The UMKDF was developed through systematic literature synthesis and secondary comparative case study analysis rather than through direct engagement with Montessori educators, architects, inclusive education specialists, children, or other end users. Consequently, the present findings establish a theoretical and analytical foundation for the framework but cannot demonstrate its stakeholder acceptability, practical usability, or effectiveness in real-world educational settings. These aspects require independent empirical validation in subsequent research.

Although the revised UMKDF explicitly maps its architectural inputs to all seven Principles of Universal Design, the Montessori-specific operationalization and relative importance of these principles are derived from secondary evidence rather than empirical stakeholder validation. Their contextual applicability and performance thresholds therefore require further empirical testing.

A further limitation concerns the retrospective scoring procedure. The classifications were performed by the authors using predefined operational criteria and documented secondary evidence rather than by multiple independent assessors. Although the operational rubric was introduced to reduce interpretive discretion, inter-rater reliability was not evaluated in the present study. Future empirical validation should therefore apply the rubric through multiple independent assessors and report inter-rater agreement, alongside direct environmental, spatial, and behavioural measurements.

Future research should adopt a sequential empirical validation strategy. First, semi-structured interviews and focus-group discussions with Montessori educators, architects, and inclusive education specialists should assess the clarity, relevance, feasibility, and contextual adaptability of the UMKDF. Second, the framework should be implemented or retrospectively evaluated in operational kindergarten settings through Post-Occupancy Evaluation (POE). Such evaluation should combine spatial and environmental measurements with behavioural and educational indicators. Quantitative measures may include A-weighted noise levels [dB(A)], duration of on-task attention, observed circulation conflicts, recorded accident or minor-injury incidents, accessibility barriers, and observable frustration events. Where ethically approved and methodologically appropriate, age-appropriate learning or cognitive measures may also be examined. Longitudinal follow-up could further determine whether any observed benefits persist over time. Together, these data would enable future studies to test whether greater architectural fidelity to UMKDF principles is associated with improved accessibility, safety, concentration, user experience, and educational outcomes.

Inconsistencies of specific non-academic outcomes such as the observed instance where some Montessori students showed slightly less persistence on a difficult, unvalidated puzzle task, despite the method's philosophical alignment with mastery and determination are also seek by the researchers to resolve the issue, (Lillard et al., 2025). To sum up, the studies must concentrate on creating systemic techniques to flourish wayfinding abilities through spatial design which is a current gap in architectural documentation (Jojy & Prakash, 2025).

CONCLUSION

The research has identified an important architectural and pedagogical gap between the distinctive spatial requirements of Montessori education and the contemporary mandate for comprehensive inclusion guided by Universal Design (UD) and Universal Design for Learning (UDL). The gap also reflects the absence of a systematic methodology for translating the theoretical compatibility between Montessori pedagogy and the principles of Universal Design (UD) and Universal Design for Learning (UDL) into measurable, failure-resistant architectural criteria. The UMKDF was developed to address this gap. The UMKDF represents a novel conceptual and scientific contribution by providing a structured, reproducible framework for designing inclusive early childhood environments.

The UMKDF's architectural-operational structure follows a sequence: integrating foundational principles (Inputs), translating them through rule-based spatial

strategies (Transformation Mechanisms, such as Kinetic and Non-Linear Planning), and verifying compliance via a Design Control System (e.g., Anthropometric Detailing).

The framework also incorporates risk-management layers (e.g., Acoustic Engineering Control, Sightline Integrity Check) that are designed to mitigate foreseeable failure scenarios and help ensure that the environment supports, rather than compromises, pedagogical goals (e.g., reducing noise-related stress in open plans). The UMKDF is designed to support equitable access to the educational benefits of Montessori by addressing physical and sensory barriers. In this framework, inclusivity extends beyond physical accessibility to encompass mobility, sensory/perceptual, cognitive/learning, and emotional/self-regulatory needs, thereby providing a broader interpretation of Universal Design within Montessori kindergarten environments.
At its current stage, the UMKDF should be regarded as a theoretically and analytically derived design framework rather than an empirically validated building standard. Therefore, broad policy adoption should follow, rather than precede, empirical testing. Future research should first examine the framework through evaluation by experts and relevant stakeholders and pilot application in operational kindergarten settings. Subsequent post-occupancy evaluation (POE) should combine environmental measurements, behavioural observations, safety and accessibility indicators, and appropriate educational measures to determine whether greater fidelity to UMKDF principles is associated with improvements in accessibility, safety, concentration, user experience, and learning outcomes. Evidence generated through such studies can then inform further refinement of the framework and its potential translation into architectural design guidance or policy.

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