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Design Strategies for Color Use in Residential Interiors

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Abstract

This study aims to propose color design strategies by examining the relationship between color preferences, user psychology, and spatial perception in residential interiors. Colors were evaluated holistically, not only by their basic types (hue) but also by their value (lightness/darkness) and saturation. The analyses reveal that warm colors are suitable for social interaction and dining spaces, while cool colors should be preferred in resting, sleeping, and working spaces. The research findings indicate that the same color type can elicit different psychological and physiological responses at different value and saturation levels, and that color effects vary significantly depending on the space's function, user profile, and contextual factors. Based on these findings, the study provides practical color strategies to optimize the user experience for different residential spaces (living rooms, bedrooms, workspaces, etc.).

Keywords: *Space color, Residence, Color effect, Color components.*

Konut Mekânlarında Renk Kullanımına Yönelik Tasarım Stratejileri

Öz

Bu çalışma, konut iç mekânlarında renk tercihleri ile kullanıcı psikolojisi ve mekânsal algı arasındaki ilişkiyi inceleyerek, renk tasarım stratejileri önermeyi amaçlamaktadır. Çalışmada, renkler yalnızca temel türleriyle (hue) değil, değer (açıklık/koyuluk) ve doymuşluk bileşenleriyle birlikte ele alınarak bütüncül bir şekilde değerlendirilmiştir. Yapılan analizler, sıcak renklerin sosyal etkileşim ve yeme-içme mekânları için uygun olduğunu, soğuk renklerin ise dinlenme, uyuma ve çalışma alanlarında tercih edilmesi gerektiğini ortaya koymaktadır. Araştırma bulguları, aynı renk türünün farklı değer ve doymuşluk düzeylerinde farklı psikolojik ve fizyolojik tepkilere yol açabildiğini, renk etkilerinin mekânın işlevi, kullanıcı profili ve bağlamsal faktörlere göre önemli ölçüde değişkenlik gösterdiğine işaret etmektedir. Çalışmanın sonucunda, bu bulgulardan hareketle, farklı konut mekânları (oturma odası, yatak odası, çalışma alanı vb.) için kullanıcı deneyimini optimize etmeye yönelik pratik renk stratejileri için uygulanabilir bir kılavuz sunulmaktadır.

Anahtar kelimeler: *Mekan rengi, Konut, Renk etkisi, Renk bileşenleri.*

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1. Introduction

Residential space is not merely a physical structure, it is a multidimensional collective of spaces that fulfills an individual's fundamental needs for security, privacy, and belonging while encompassing all functions of daily life. As the setting where people spend more than half of their lives, the residential environment hosts a wide array of activities, and its multifaceted design directly shapes both individual experience and behavioral and emotional processes. Consequently, residential interiors, with areas designated for sleeping, dining, socializing, reading, watching television/movies, studying, and increasingly, working, respond to diverse needs through design components such as form, color, texture, and lighting. The holistic composition of these components creates not only perceptual but also psychological and physiological effects on the user. Within this holistic framework, color, in particular, stands out as one of the most fundamental design elements that determines the perception of a space, guides user attitudes and behaviors, and shapes the identity of a residence. Mahnke (1996) defined color as a phenomenon 'created by light and an energy form that affects bodily functions and directs mental and emotional processes,' emphasizing its influence on the nervous system and hormonal activities. In this context, the colors used in interior spaces are not merely an aesthetic element but a powerful tool that directs users' physiological responses, moods, and spatial perception. The color of a space can create a stimulating effect by increasing heart rate, a relaxing effect by slowing it down, or at times, a cheerful effect, while also mediating the perception of the space as gloomy, peaceful, spacious, or bright.

The effects of color in a space extend beyond its physiological and emotional dimensions, directly relating to its functional context. The purpose of a space is a decisive factor in color selection. While more neutral and calming colors are suitable for study areas that require intense attention and mental focus, vibrant and stimulating colors are prominent in spaces for socializing, dining, or entertainment. In relaxation and sleeping areas, serene colors that provide peace and tranquility are prioritized, while circulation areas utilize color schemes that guide movement and increase dynamism. This context demonstrates that color selection is a strategic tool that shapes the user experience according to the intended use of the space.

Interior wall colors, as a design component, hold a significant place in spatial perception due to the large surface area they cover. As noted by Hutchings et al. (2012), walls are a design component of interiors through their colors. Walls have been the backdrop of human life since humanity began living in caves (Ulusoy et al., 2020). They provide a background for the objects within the space, playing a role in highlighting them or making them recede. In this context, color studies for interior spaces are largely based on wall colors.

On the other hand, color preferences vary from person to person, from culture to culture, and according to geographical conditions and spatial context. For example, an individual who likes purple may use this color in their clothing choices but may not show the same inclination when choosing a car or interior color. Studies conducted independently of context have shown that blue tones are generally preferred, and the main reason for this is that the sky, seas, and clean water sources are blue (Palmer & Schloss, 2010). However, the colors used in living spaces vary depending on the function of the space, the color-texture characteristics of furniture and fixtures, and the psychological impact of the space on the user. Therefore, color selection in residential interiors should be considered as a holistic design decision that supports the function of the space and guides the user experience.

1.1. Theoretical Framework of Color

To understand the effects and perception of color in architecture, it is first necessary to grasp color science. The subject of color is a broad and profound scientific field, extending beyond simple adjectives like red, blue, or purple used to identify an object or surface. The word "renk" in Turkish is derived from the Persian word "reng." The Greek word "chroma" means color, and the term "chromatic" refers to having a color other than black, white, and gray. To perceive, define, or use color, one must understand its various properties. Scientifically, colors are addressed in two forms: light colors and surface colors. Color is a property of light, and the specific color is determined by the light's

wavelength. The visible spectrum, or colored radiation, constitutes the region between 360-780 nm of the electromagnetic spectrum (Figure 1).

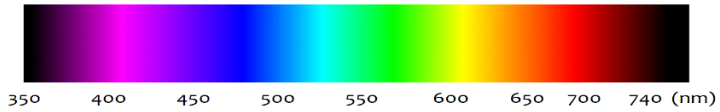


Figure 1. Visible spectrum of radiation and wavelengths of colors (Created by the Author)

Color, an intermediary that surrounds our visual world and helps us distinguish, define, and even form emotional connections with objects or surfaces, consists of light stimuli that originate from a light source, strike surfaces/objects, and are reflected to our eyes, stimulating our brain through the visual system (Figure 2). The contrasts between colors in our environment also help us define and evaluate our surroundings. A bird's ability to spot a red berry among green plants and survive stems from the perception created by this color contrast (Mahnke, 1996). Similarly, the widespread use of yellow for taxis in many parts of the world is due to this color being in the area to which the visual system is most sensitive, making it more visible than other objects and allowing users to notice it from a distance.

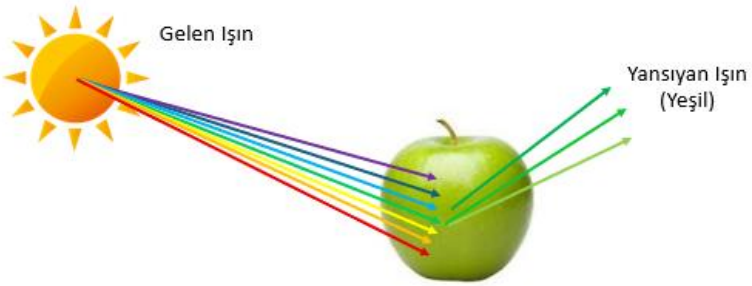


Figure 2. Reflection of light from a surface (Created by the Author)

Color perception is a complex process that influences how we interpret and experience our environment, and its foundation is shaped by both scientific and artistic approaches. The first systematic studies on color began with Isaac Newton's separation of white light with a prism, which established color as a physical reality. The "Young-Helmholtz Three-Color Theory," developed by Thomas Young and Hermann von Helmholtz, proposed that three types of cone cells in the eye (red, green, blue) are sensitive to different wavelengths (Wandell, 1995), while Ewald Hering's "Opponent-Process Theory" argued that colors are processed in opposing pairs (red-green, blue-yellow) (Hering, 1878). In addition to these scientific approaches, concepts such as hue, value (lightness/darkness), and saturation were first brought together in Philipp Otto Runge's Farbenkugel (Color Sphere) model (Gage, 1999). Subsequently, the Munsell Color System developed by Albert H. Munsell (1915) and the CIE 1931 Color Space created by the International Commission on Illumination (CIE) enabled the quantitative and objective definition of colors (Fairchild, 2013). All these developments demonstrate that color is not merely a visual element in spatial design but a physiological and psychological tool based on scientific principles.

1.2. Color Compenents

To comprehend color more effectively, it is insufficient to define it merely with basic designations like red, yellow, or blue. Color can be understood more comprehensively when examined beyond these simple classifications, by considering its different components. For this reason, the systematic explanation of the color phenomenon becomes apparent in systems like the Munsell Color System (Munsell, 1915).

The chromatic properties of both light and surface colors are defined by three components that can vary independently of each other: hue, value (lightness/darkness), and saturation. Hue specifies a color's fundamental identity, such as its name, like red, yellow, or green. Value indicates how light or dark a color is. This component also expresses the amount of black or white within a color. In the Munsell system, value is defined by a ten-step gray scale between black (0) and white (10). For example, increasing the value of red turns it into a lighter shade, or pink. Saturation, on the other hand, expresses a color's purity or intensity. This determines how vivid or how dull a color appears. A color

with low saturation contains more gray and looks duller, while a high-saturation color looks more vivid and pure. In the Munsell system, saturation increases as one moves away from the gray axis on a hue page. For example, increasing the saturation of a red turns it into a brighter and more intense red (Figure 3).

Colors are defined by color ordering systems. In these systems, similar colors are placed next to each other, and color changes or perceptual steps are arranged in a sequential manner. Colors defined in a specific order are matched with particular coordinates in space and transformed into a three-dimensional system called a "color solid" (Figure 3). The Munsell Color System, one of the surface color systems, was created based on the decimal system in accordance with equal perceptual steps. In this system, defined by hue, value, and saturation components, each hue is shown with its different values and saturations on a single page (Figure 4). In the Munsell color system, on any hue page, as one moves away from the value bar extending from black to white, the proportion of gray in the color decreases, and the purity, or saturation, of the color increases. In the red hue (Munsell 7R) page in Figure 4, it can be seen that as one moves from low to high saturation, the red color becomes purer, i.e., its saturation increases. If the proportion of white within a specific hue and saturation is increased, the color will lighten; in other words, its value will increase. For example, the dark red of a red hue, maroon, will evolve toward pink (Figure 4).

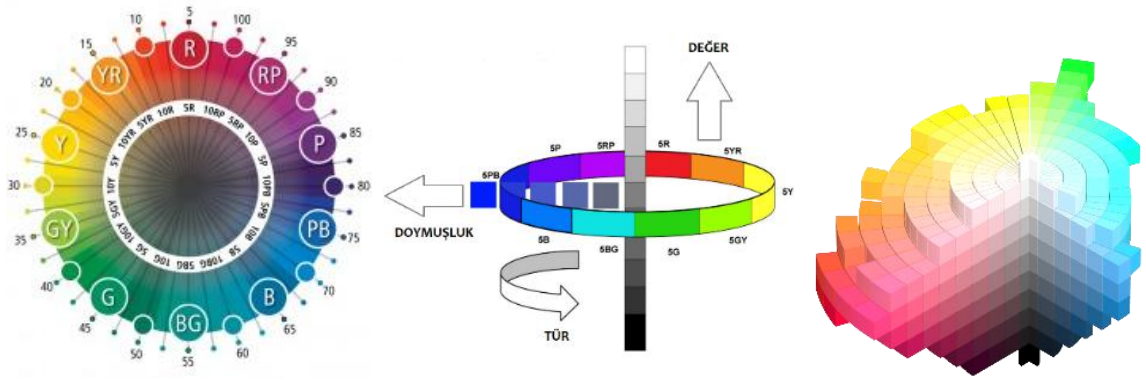


Figure 3. Munsell Color System (Munsell Color, 2025)

Most fundamental color terms are based on hue or refer to it (e.g., red, orange, yellow), but some describe lightness (e.g., pink is a light red, brown is a dark yellow or orange) or color saturation (e.g., gray, light blue) (Jonauskaite & Mohr, 2025). However, a single hue is defined across a very broad color scale with different values and saturations.

Considering the explanations above, defining color only in terms of hue—such as red or yellow—is a very superficial approach, given that the human visual system can distinguish up to 2.5 million color sensations (Pointer & Attidrige, 1998; Linhares et al., 2008). In this context, the relationship established in the context of hue, value, and saturation, rather than just hue, will play an effective role in understanding color's effect on humans and the studies to be conducted in color design within a specific systematic framework.

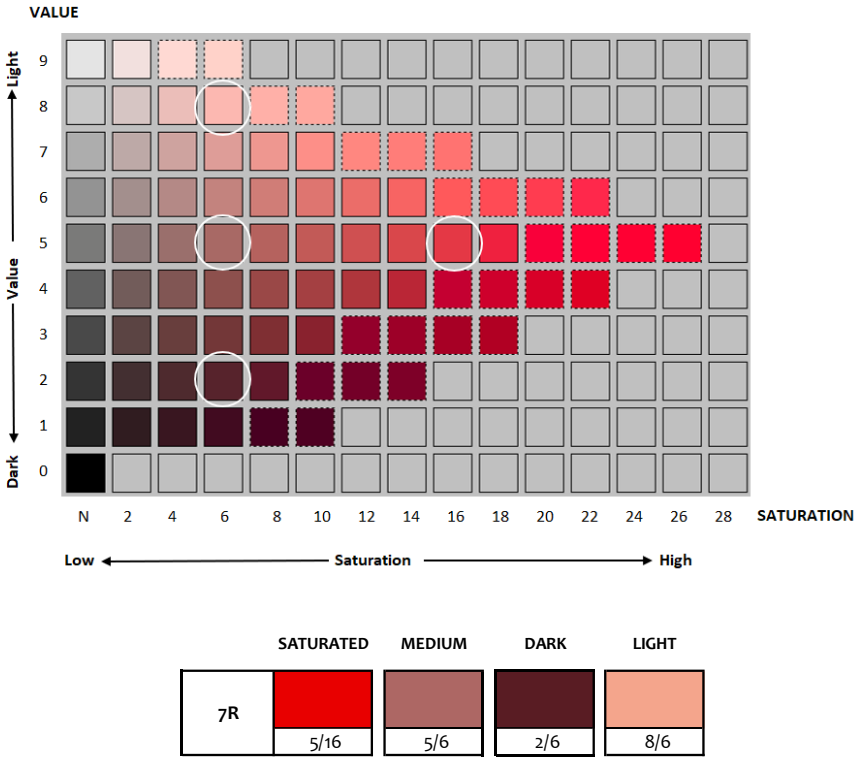


Figure 4. Colors of the red type (Munsell 7R) with different values and saturations (Created by the Author)

1.3. Use of Color in Interiors and Residential Spaces

Interior colors are one of the most fundamental elements shaping the spatial experience. Colors not only affect visual perception but also influence individuals' psychological states, physiological reactions, and behaviors within a space (Mahnke, 1996; Kaya & Epps, 2004). Therefore, in interior design, color emerges as a powerful design parameter that must be evaluated in conjunction with its functional, physiological, and psychological dimensions. The literature, particularly studies on color preferences in residential spaces, indicates that colors have a direct effect on individuals' quality of life and perception of spatial comfort (Yıldırım et al., 2011; Jonauskaite & Mohr, 2025). Consequently, examining the psychological associations created by different color in interiors and their contribution to user experience is significant from both a theoretical and an applied perspective.

A color's hue is defined by its wavelength in the light spectrum. Colors with short wavelengths are associated with "cool" colors. The shortest wavelength color is violet (360-400 nm), followed by blue (400-480 nm) and green (520-565 nm). The longest wavelength is red (625-740 nm), followed by orange (590-625 nm) and yellow (565-590 nm), which are associated with "warm" colors (Nakasian, 1964; Crowley, 1993; Yıldırım et al., 2011). Cool colors (blue, green) generally have calming, peaceful effects, while warm colors (red, orange, yellow) have stimulating, energizing effects. These general psychological effects are consistently observed in studies on interior color perception (Valdez & Mehrabian, 1994; Nelson et al., 1984). Research on color use in spaces indicates that colors with short wavelengths are predominantly preferred by users. This preference suggests a general relationship between mood and wavelength in spatial perception (Valdez & Mehrabian, 1994). Experimental research suggests that, in parallel with the relaxing effect of the natural environment, such as the blue sky and vast green vegetation, cool colors with short/medium wavelengths like blue and green have a calming effect and make an interior space appear more peaceful (Yıldırım et al., 2011; Ulusoy et al., 2020; Jonauskaite & Mohr, 2025). Depending on its value and saturation components, the color blue can, in some cases, also create a melancholic and somber effect, making the space feel dull, static, and boring (Manav, 2015).

A great deal of evidence in the literature shows that colors have strong effects on individuals' emotional states (Jonauskaite & Mohr, 2025; Valdez & Mehrabian, 1994; Mahnke, 1996; Kaya & Epps, 2004). Levy's (1984) study demonstrated a systematic relationship between color and emotion, finding

that warm colors, especially red, activate more active emotions like "anger," and yellow, "sadness," while cool colors evoke feelings of "calmness" in blue tones and "serenity" in purple tones. Jonauskaite & Mohr's (2025) comprehensive literature review systematically presents common inferences about the color-emotion relationship. According to their review, yellow, green, green-blue, blue, and pink colors, as well as white, light/bright, and saturated colors, are more frequently associated with positive connotations, whereas brown, gray, black, and dark colors tend to create more negative associations. Furthermore, red, yellow, and saturated colors in general are linked to high arousal levels, while blue, green, white, and gray are associated with low arousal.

Red is the most debated color in the literature, with both positive and negative connotations. While it is attributed with positive effects such as increasing blood pressure, and being stimulating, powerful, passionate, and appetite-inducing, it can also trigger negative emotions like aggression, hyperactivity, and anger (Kaya & Epps, 2004). Research by Küller et al. (2009) in rooms painted with saturated red found that red increased brain activation and heart rate. In contrast, pink, a low-saturation and high-value tone of red, creates a different effect with its calming and happiness-inducing properties. Indeed, Schauss's (1979) study in a prison setting reported that pink wards reduced aggression and aggressive behavior among inmates.

Many studies on color show that green is most associated with nature (Sakarya & Canpolat, 2015; Kaya & Epps, 2004). The renewal and freshness of nature express this color's association with concepts such as peace, harmony, relaxation, freshness, silence, contentment, happiness, and hope in a space (Ulusoy et al., 2020). While green gives positive results in creating a serene environment, its intensive use can create laziness and sluggishness (Manav, 2015).

In interior design, the effect of color has been examined by classifying it primarily based on hue in many studies. However, this approach may be insufficient to fully explain color's perceptual and psychological effects, as the same hue can create entirely different experiences and contrasting effects at different value and saturation levels (Elliot, 2015). For instance, a high-saturation red can have a stimulating and aggressive effect, while a low-saturation, high-value red (e.g., pastel pink) can be calming. Therefore, considering the hue, value, and saturation components together is of critical importance for understanding color's effect.

Kaya & Crosby (2006) investigated color preferences in residential buildings and found that preferences were shaped more by value and saturation than by hue. The study showed that low-saturation and light colors provided a low arousal level, but this did not always align with a calming home atmosphere, indicating a complex interaction. Al-Ayashi et al. (2016) stated that users perceived all high-saturation colors as "vibrant," regardless of whether they were warm or cool. The same study reported that high-saturation yellow and red tones were found to be disturbing and unsuitable for work environments. The findings of Valdez & Mehrabian (1994) support this view. These results suggest that the primary determinant of color effect is not hue but rather saturation and lightness.

Some studies have shown that gender differences also play a decisive role in color preferences. Duyan & Ünver's (2018) study on living room color preferences found that female participants preferred warm colors (red, orange, yellow), while male participants leaned toward medium and high-value tones of cool colors (especially blue and blue-violet). Similarly, in their studies on dormitory buildings, Costa et al. (2018) found that women preferred purple hues more intensely compared to men, while men showed a more pronounced inclination toward blue hues. However, the literature on such gender-based differences is limited.

The relationship between the color of a space and its function is one of the key elements that guide user experience in interior design. Colors are not merely emotional, meaningful, or perceptual, they are also functional tools that support the intended use of the space and guide user behavior (Kwallek, Lewis & Robbins, 1997; Manav, 2007). For example, the preference for cool hues like blue and green in work areas is associated with increased focus and productivity, while the use of warm hues like red and orange in social areas promotes vibrancy and interaction. Similarly, it has been reported that light and neutral colors used in healthcare spaces create a calming atmosphere by reducing stress levels (Dalke et al., 2004; Aydoğdu, 2024). Kaya & Crosby (2006) examined 18 different colors and various

building types (residences, restaurants, religious buildings, hospitals, hotels, shopping malls, educational structures, entertainment venues, official buildings, and factories) and found that color preferences were linked to emotional associations, and these associations were influenced by the knowledge individuals gained from their color experiences in the built environment. In this context, it can be stated that selecting colors that are compatible with the function of the space positively affects both the effective use of the space and the psychological and behavioral reactions of the users.

Color is a powerful tool for manipulating the perceived physical properties of a space. It is known that different hues and their use at high/low values or high/low saturation affect the perception of a space as large/small, narrow/wide, bright/dark, or focusing/distracting. Studies on the perception of room size have shown that cool hues like blue and green have a relaxing and refreshing effect by making the space appear larger (Kaya & Epps, 2004). Studies with warm colors suggest a tendency to make an interior look narrower but more active (Nelson et al., 1984; Whitfield & Wiltshire, 1990; Crowley, 1993). Freiling stated that painting all walls in warm tones creates a surrounding, unifying, and visually restrictive effect (Freiling, 1979). Gage (1999) suggested that dark colors help gather attention and make boundaries perceptually more defined. The literature also emphasizes that dark colors make the ceiling appear lower (Evans & McCoy, 1998). Specifically, dark and warm colors (e.g., dark red, brown) can make surfaces stand out, making the space feel narrower, lower, and more intimate (Mahnke, 1996). In general, some studies have stated that light and cool colors (e.g., light blue, lavender) push surfaces back, making the space appear wider and higher and increasing the sense of spaciousness (Gage, 1999; Savavibool & Moorapun, 2017). High-saturation (vivid) colors reinforce the feeling of narrowness and intensity in spatial perception, while low-saturation and high-value colors create a more expansive, calm, and refreshing feeling, thereby having a soothing effect (Küller et al., 2009).

Research focusing on residential spaces shows clear differences in color preferences according to different room functions. A study on residential interiors examined the color suitability of living rooms and bedrooms and concluded that the use of a color changes according to the function of a room (Slatter & Whitfield, 1977). In Manav's (2007) study, participants preferred pink (high-value red) for bedrooms, light blue for living rooms, and light yellow for dining areas. Similarly, Torres et al.'s (2020) research in a nursing home revealed that warm colors (yellow, orange, red) were preferred in social living areas, while cool colors (blue, purple, green) were preferred in bedrooms. In a study on spatial color preference, participants associated cool colors and blue with residences, hotels, and hospitals, and warm colors and red with entertainment buildings like restaurants, theaters, and shopping malls. The study also found that purple was the least preferred color for residential building types, whereas blue (due to its calming associations like peace and relaxation) or red (due to participants' prior experiences with brick colors) emerged as the most preferred colors (Kaya & Crosby, 2006).

A study by Costa et al. (2018) revealed that blue and green were the most preferred colors in dormitory rooms. Ulusoy (2024), in a color study on geometric wall surfaces in bedrooms, determined that the most preferred colors were purple, followed by brown and blue. This shows that color preference can vary depending on the context (e.g., shape). Another study by Ulusoy et al. (2020) emphasized that the color green creates positive emotions in interiors, referencing 'home,' 'peace,' and 'joy of life.' The results of the same study suggest that purple should be used more carefully in residential spaces (Ulusoy et al., 2020). In their study on living room colors, Yıldırım et al. (2011) described warm color schemes as "high arousal," "exciting," and "stimulating," while cool colors tended to be associated with "not very exciting," and were also described as "spacious" and "relaxing." Generally, the literature assumes that cool and achromatic colors evoke more calm and peaceful feelings (Yıldırım et al., 2011).

Interior colors are influenced by many contexts, including individual preferences, function, gender, cultural background, and spatial perception. However, studies conducted specifically on the dimension of spatial function indicate the existence of some objective tendencies in the evaluation and preference of colors. As a powerful design parameter that directly affects users' psychological and physiological comfort, color emerges as a fundamental element in residential spaces that supports functional differences, defines the identity of the space, shapes its atmosphere, and guides its use. The conscious and strategic use of color enriches the spatial experience while supporting the functionality

and success of architectural design. This study aims to provide a comprehensive theoretical framework for color use in residential spaces, conduct a systematic analysis of the studies in the literature, and develop design strategies for color use in residences in light of the findings. The goal is to create a comprehensive resource, both academic and practice-oriented, that will provide guidance in color selection within the context of different usage areas and functions in residences.

2. Method and Method

This study adopts a qualitative approach to analyze color knowledge from a theoretical foundation, conducting a systematic literature review on its use in residential spaces. The methodology is structured in two phases.

In the first phase, national and international studies in color theory, color psychology, and spatial design were reviewed to define the psychological and physiological effects of each color for residential use. This phase identified fundamental colors used in interior spaces and correlated them with their functional applications in a residential context.

The second phase involved analyzing the effects of colors on user experience (e.g., stimulating, relaxing, calming) and matching them with appropriate application areas within residential spaces. The data gathered from the literature review were categorized using the Munsell Color System as a reference, including chromatic primary colors (red, yellow, green, blue, purple), intermediate colors (orange, yellow-green, blue-green, blue-purple, and red-purple), and achromatic colors (white, gray, black). The psychological and physiological effects of each color were systematically organized into a tabular format, providing a framework that highlights the functional roles of colors in a residential context.

3. Findings and Discussion

A literature review on residential interiors examined numerous studies and conducted comprehensive evaluations of colors in terms of their functional, affective, and component-based properties. Accordingly, the relationship between color and function is seen as a particularly important factor in interior design. While the spatial arrangement of residences is often shaped by individual or family preferences, existing studies show that color perception reveals not only subjective differences but also certain objective tendencies.

3.1. Evaluation of Colors in Residential Spaces

Studies on the effects of interior colors on users show that warm colors have stimulating, activating effects (Figure 5), while cool colors have calming, relaxing effects (Jonauskaite & Mohr, 2025). Many studies indicate that red, at medium to high saturation, is stimulating, and yellow and orange are slightly stimulating but also cheerful (Silters et al., 2023; Jonauskate & Mohr, 2025).



Figure 5. Interiors using warm colors; Left and right (Hygee & Home, 2025), middle (Stylishspaceglobe, 2025)

In the literature, it is reported that the effects of red, the most stimulating of the warm colors (especially its saturated tones), can be both positive and negative (Jonauskaite & Mohr, 2025).

Specifically, red is suggested to negatively impact activities requiring fine psychomotor coordination and cognitive performance (Elliot, 2015; Yıldırım et al., 2011; James & Domingos, 1953; Nakashian, 1964). A study in primary school classrooms found that red wall color distracted students and led to hyperactivity (Duyan & Ünver, 2022). Similarly, research by Küller and colleagues in rooms painted red showed that this color increased brain activity (Küller et al., 2009). However, red's metabolism-accelerating and stimulating effect is positively evaluated as an appetite stimulant, which is why it is frequently recommended for use in dining spaces like restaurants and cafeterias (Elliot, 2015). The effects of pink, a high-value (light) tone of red, and maroon, a dark tone, differ from that of saturated red. In the literature, pink is associated with positive emotions (Jonauskaite & Mohr, 2025), while dark red, similar to other dark colors, creates a focusing and space-constricting effect (Gage, 1999; Duyan & Işık, 2024).

Yellow and orange are reported in many studies to have a high potential for arousal as warm colors (Jonauskaite & Mohr, 2025). Yellow, the color of the sun, is generally associated with happiness and energy, and stands out for its positive effects on individuals (Boyatzis & Varghese, 1994). Due to yellow's warmth and its association with the sun, it is noted that it can make users perceive a space as warmer than it is. Additionally, some research has shown that yellow has a supportive effect on mental activity (Duyan & Ünver, 2022). Orange, formed by the combination of long-wavelength red and yellow, is evaluated as a color associated with dynamism, energy, joy, and creativity (Figure 5). However, it is also emphasized that high saturation and intensive use of orange can cause restlessness (Manav, 2015).

In light of these findings, it can be said that medium and saturated colors of red and other warm colors are suitable for use in residential interiors, particularly in spaces where socialization and dining are prominent, such as living rooms and dining rooms. In contrast, limiting the use of red in spaces where focus and tranquility are important, such as study, relaxation, or sleeping areas, will provide a more balanced design approach. When warm hues are examined based on their value and saturation components, it is reported that light colors of red (pink) have a calming effect (Schauss, 1979). Therefore, warm colors with high value and low saturation may be appropriate for use in bedrooms, relaxation, and study areas. Figure 6 shows the different effects created by the use of light, medium/saturated, and dark tones of red in a bedroom.



Figure 6. Light, saturated and dark shades of red (Created by the Author)

In contrast to warm colors, cool colors such as purple, blue, and green have been shown to have 'relaxing' and 'calming' effects in numerous studies (James & Domingos, 1953; Nakashian, 1964). Blue, in particular, has been highlighted in various studies for its association with improved mood and a sense of tranquility (Rosenstein, 1985; Stone, 2003). Manav's (2007) research also indicated that participants gravitated more toward cool blue colors in living rooms. Similarly, a laboratory study by Küller et al. (2009) revealed that blue rooms had a calming effect on users, reducing their heart rate. It is generally accepted in the literature that while warm colors create a more dynamic atmosphere in a space, cool colors shape spatial perception in a more static, peaceful, and positively associated manner with low arousal levels (Jonauskaite & Mohr, 2025).

The relaxing, calming, and refreshing effects of the blue, blue-green, and green color palette form the primary rationale for their preference in residential interiors, especially in bedrooms, relaxation rooms,

and study rooms (Figure 7). Green's association with happiness is another strong reason supporting its use in all other spaces of the home (Ulusoy, 2020).

Purple, classified within the cool color group, exhibits properties partially similar to other short-wavelength colors in terms of spatial perception and psychological effects (Figure 7). This color, which ranges across a wide spectrum from red-purple to blue-purple, also offers a variety of color options due to its rich saturation scale. Influenced by its red and blue pigments, purple can evoke feelings of calmness and joy, but also sadness and fatigue. Findings in the literature suggest that purple encourages creative thinking (Levy, 1984; Kaya & Epps, 2004). However, despite studies showing a significant relationship between this color and empowering and motivating emotions, users generally avoid using purple in residences (Ulusoy et al., 2020; Jonauskaite & Mohr, 2025).



Figure 7. Examples of interiors in cold colors (Left (Decoholic, 2025), center (Defrente Para Omar, 2025), right (Haus und Gartentrend, 2025))

Formed by the combination of two colors at the beginning and end of the light spectrum, red-purple has been associated with positive emotions such as happiness, love, and serenity, as well as partially with depressive connotations (Kaya & Epps, 2004). A study in primary school classrooms found that red-purple wall color calmed students and helped them focus (Duyan & Ünver, 2022). Furthermore, the lighter tones of this color fall into the pink range, reinforcing its calming potential (Schauss, 1979). Based on these findings, it can be suggested that red-purple may yield positive results, especially in spaces designated for rest, work, and sleep.

Achromatic colors refer to the neutral color group that lacks hue and includes different tones of black, white, and gray. These colors, which range from white to black, are defined solely by the value variable because they lack saturation (Figure 8). Consequently, in spaces designed with a purely achromatic palette, other design elements such as form, texture, and light-shadow contrast take precedence over the psychological or perceptual effects of color (Yıldırım et al., 2011). Nevertheless, it is acknowledged in the literature that achromatic colors have certain emotional connotations. For example, the study by Wilms & Oberfeld (2018) showed that achromatic colors caused a brief slowing of heart rate, a condition linked to a low arousal level. This finding suggests that the intensive use of achromatic colors might create a feeling of stagnation and sluggishness in a space. Other studies indicate that gray is typically associated with low arousal and negative emotions (e.g., lifelessness, melancholy), black with high arousal but negative connotations (e.g., power, authority, fear), and white with high arousal and mostly positive connotations (e.g., purity, spaciousness, emptiness) (Jonauskaite & Mohr, 2025).



Figure 8. Achromatic color schemes in the space. On the left, white (Freepik, 2025), in the middle, gray (Haus und Gartentrends, 2025), on the right, black (Hgyee & Home, 2025)

Black, a color that absorbs the majority of all incoming light, is generally associated with death, and thus linked to sadness, depression, fear, anger, mourning, and tragic events, as well as darkness and night (Kaya & Epps, 2004). Positively, it is associated with concepts of power, elegance, and richness. Dark gray and low-saturation colors are similarly regarded and can reflect similar characteristics. From both a design and a lighting technology perspective, black is not highly suitable for use in residences.

Gray, which spans a scale from light to dark, is primarily associated with emotions and concepts such as sluggishness, sadness, depression, fatigue, loneliness, and bad/rainy weather. In an experiment by Adams & Osgood (1973), red was found to be the most active color for a sample group, while black and gray were the most passive. However, in terms of value, gray is also associated with "independence, separation, loneliness, and self-criticism" from white (light) to black (dark) (Chiazzari, 1998; Kaya & Epps, 2004). Gray colors are known for their neutral nature and can serve as an excellent background to highlight other colors (Enwin et al., 2023).

White, the complete opposite of black and a symbol of light and brightness, is associated with innocence, peace, hope, purity, silence, and cleanliness. In general, it is linked to positive, low-arousal emotions (Hemphill, 1996; Jonauskaite & Mohr, 2025). As a color that reflects all incoming light, white tends to make a space appear larger and more spacious. In a study by Kwallek et al. (1997), participants found a white office unsettling and made more errors. This finding suggests that white may not be suitable for use in spaces like workspaces or bedrooms, as very bright rooms can be distracting.

In Northern geographies, particularly in Scandinavian countries, there is a strong preference for light colors—most notably white—in interior spaces (Figure 9). The primary functional reason for this preference is the high light-reflectance property of light colors. This feature maximizes interior light levels even during the long winter months when daylight is extremely limited, thereby enhancing spatial perception and promoting positive psychological effects. These geographical and climatic necessities have evolved into an aesthetic principle, playing a fundamental role in the emergence of the Scandinavian Design Style. Within this style, white and other light colors dominate large surfaces, while darker tones are applied sparingly and strategically to generate contrast. Natural materials such as wood, wool weaves, and furry textiles are frequently used to add warmth, tactility, and an organic naturalness to the space (Figure 9). Consequently, the prevalence of white and light color use in these regions should be considered a functional and highly adaptive response to geographical and climatic conditions.



Figure 9. Scandinavian style interior (Lavi Tasarım, 2025)

The explanations and scientific findings presented above demonstrate that a more comprehensive and valid approach to defining colors involves considering them in the context of their components, particularly value and saturation, rather than solely through basic hue categories like red or green. Indeed, various studies have shown that colors with the same hue but different value and saturation levels have significantly different cognitive and emotional effects (Elliot, 2015; Palmer & Schloss, 2010). This finding suggests that a reductionist, hue-focused approach is insufficient in color research, whereas multidimensional and holistic analyses yield more reliable results. Therefore, to gain a deep understanding of the psychological and physiological effects of colors, a systematic research framework that considers hue, value, and saturation components together needs to be developed, as saturation and value are critical factors that directly shape a color's psychological and physiological impact (Elliot, 2015).

Saturation refers to a color's distance from the gray scale. In this context, high saturation means the color is more prominent, eye-catching, and produces strong psychological effects, while low-saturation colors become more neutral as they approach gray, and their perceptual effects weaken. However, most studies in the literature focus on hue and do not adequately consider the saturation parameter (Elliot, 2015). Yet, in architectural and interior design, the level of saturation is a critical variable that directly determines the psychological atmosphere of a space and the user experience. High-saturation colors increase emotional responses through their stimulating effects, while low-saturation colors tend to create a calm and neutral environment. Furthermore, this effect is directly related not only to the color itself but also to the size of the surface on which it is used. High-saturation colors on large surfaces create a more intense stimulating effect, whereas this effect is relatively limited on small surfaces. However, the use of highly saturated colors on large surfaces can lead to some disadvantages in terms of lighting technology. The colored reflection of light striking a colored surface can cause color shifts on adjacent surfaces, which both distorts spatial color perception and negatively affects visual comfort and lighting efficiency (Ünver, 1985; Kwallek et al., 1997; Al-Ayash et al., 2016). Therefore, in effective spatial design, the level of saturation and the size of the surface area must be balanced appropriately with the design purpose, in addition to the hue. In this context, the limited use of high-saturation colors is suitable for residential spaces.

A color's value (lightness/darkness) has a decisive effect on spatial perception. Low-value (dark) colors give a space a heavier and narrower character while also creating a focusing effect. In this context, although the preference for dark tones in work and rest areas is considered appropriate due to their focusing effect, they are not recommended by standards for lighting efficiency and visual comfort (TS EN 12464-1:2021). High-value (light) colors increase the light reflection ratio, raising the overall light level in the space, which helps support visual comfort and contributes to the perception of the space as more spacious and large. While some studies show that light colors have more relaxing effects, their

use can still vary depending on the function (Aydoğdu, 2024; Köseoğlu & Çelikkayalar, 2016). Figure 10 shows the high and low-value interior applications of blue.



Figure 10. High (left) and low (center) use of blue hue (Munsell 10B) (Left, (House & Garden Magazine UK, 2025), medium (Mobilya günlüğü, 2025), right (Michele Clamp Art, 2025)

The combined use of different colors with similar and high values creates visual unity and a balanced atmosphere in an interior. The left side of Figure 11 shows high-value (light-toned, V:9) colors from the Munsell Color System, while the right side presents an application of these colors to a living space. The use of light colors with different hues not only gives the space a harmonious and peaceful character but also supports a spatial perception that is wider, simpler, brighter, and more tranquil.

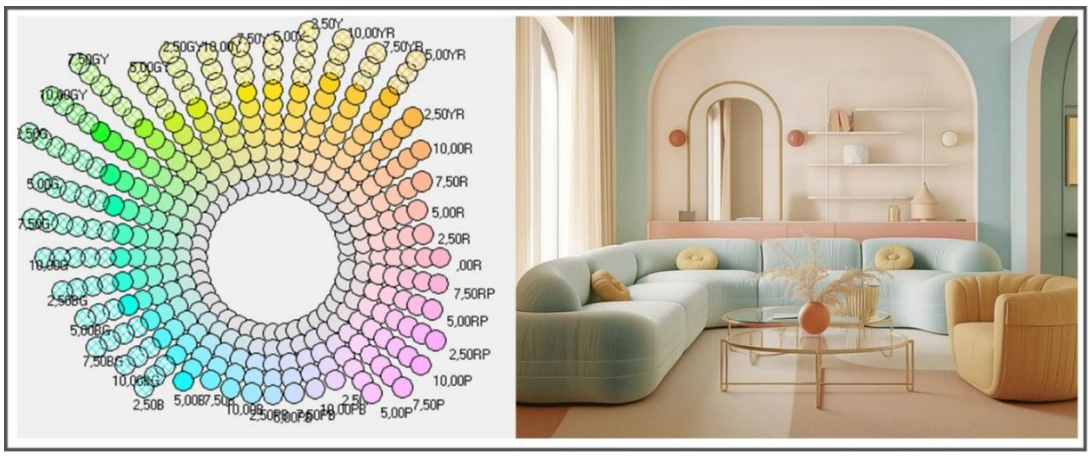


Figure 11. On the left, high value (light, V:9) Munsell colors (Wallkill Color Services, n.d.), on the right, a living space made of high value colors (Chloé, 2025)

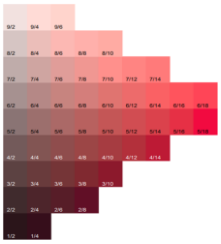
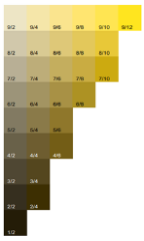
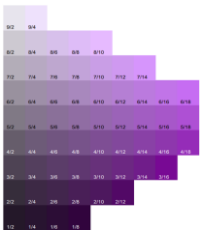
In spatial design, color selection can be viewed as a multidimensional process that requires the simultaneous evaluation of color's hue, saturation, and value components, along with a space's function, lighting conditions, and visual performance criteria. As emphasized in the literature, such a multidimensional approach can help balance the psychological effects of colors with physical conditions such as spatial perception, visual comfort, and energy efficiency (Küller et al., 2009; Manav, 2007; Elliot, 2015). This allows for higher-quality interior designs where color decisions improve user experience, enhance a space's functionality, and align with sustainability criteria.

3.2. Systematic Analysis of Colors Used in Residential Spaces

Literature findings on the colour-space-impact relationship are also applicable to residential interiors. Colour preferences in homes exhibit significant diversity based on both the function of the space and the user profile. The results of colour psychology studies can be utilised to construct an analytical framework for residential spaces.

Studies in the literature have predominantly concentrated on red and blue, while other primary colours such as yellow, green, and purple, as well as intermediate tones, have been investigated to a more limited extent. To address this gap, this study employs the Munsell Colour System to create systematic tables categorising colour use in residential spaces. The spatial effects and recommended applications of primary chromatic colours (Table 1), intermediate chromatic colours (Table 2), and achromatic colours (Table 3) are summarised based on compiled literature findings. Each selected fundamental colour is treated inclusively, encompassing its nearby hues.

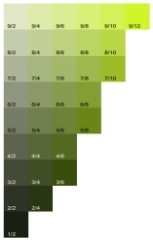
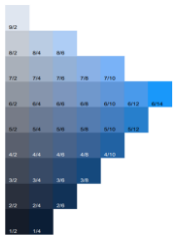
Table 1. Uses of Achromatic Primary Colors in Residential Spaces (Michele Clamp Art-Munsell, 2025)

CROMATİC PRIMARY COLOS	PROPERTIES of COLOR	COLOR EFFECT	RESIDENTAL USE AREAS
5R RED 	Energy, passion, stimulation, activity (Kaya & Epps, 2006; Valdez & Mehrabian, 1994; Küller et al., 2017)	Saturated colors are stimulating, energizing, exciting, appetite-increasing, but can also trigger anger and aggression. (Kaya & Epps, 2004; Küller et al., 2009; Jonauskaite & Mohr, 2025).	Medium/light colors of red are suitable for living and dining rooms. Highly saturated colors can be stimulating, so they should be used in smaller spaces. Lighter colors (like pink) are more suitable for bedrooms and children's rooms.
5Y YELLOW 	Liveliness, joy, optimism, attention-grabbing, happiness, and mind-stimulating (Boyatzis & Varghese, 1994). Low-value and saturated colors are associated with earth tones.	Light colors brighten spaces, while saturated colors have a vibrant, warm, uplifting, and mentally active effect. Saturated colors can be tiring with prolonged use. (Duyan & Ünver, 2022; Jonauskaite & Mohr, 2025).	Its high-value, low-saturated colors, also called beige, can be used in almost all residential spaces due to their calming effect. Medium-saturated colors can be used in living spaces.
5G GREEN 	Balance, naturalness, peace, trust, happiness (Ulusoy et al., 2020).	It has a relaxing, calming, pleasurable, and refreshing effect, reminiscent of nature. It has a positive, low-stimulation effect. (Ulusoy, 2020; Elliot, 2015; Jonauskaite & Mohr, 2025).	Colors of different values and saturations of green can be used in the living room, study and bedroom.
5B BLUE 	Calmness, serenity, confidence, coolness/coldness (Kaya & Epps, 2004; Yıldırım et al., 2011; Valdez & Mehrabian, 1994; Nelson et al., 1984)	Blue colors, which have short wavelengths, have a calming effect. They make the space look spacious and roomy (Valdez & Mehrabian, 1974; Yıldırım et al., 2011)	Different colors of blue can be used in bedrooms and study rooms for both calming and relaxing purposes.
5P MOR 	Nobility, creativity, mysticism, dramatic effect (Adıgüzel & Kolancı, 2017)	Purple, a short-wavelength blend of blue and red, has a relaxing, calming, and creative effect (Jonauskaite & Mohr, 2025; Levy, 1984). It adds depth and a sophisticated atmosphere to a space, creating emotional intensity.	Limited use in bedrooms and recreational areas may be appropriate. (Ulusoy, 2024). Studies generally discourage the use of purple in residential settings. (Kaya & Crosby, 2006; Ulusoy et al., 2020).

Intermediate colors are positioned between primary colors on the color wheel and embody the characteristics of the two primary colors that compose them. For this reason, the effects of intermediate colors within a space create a unique experience by carrying the perceptual and influential properties of their neighboring warm and cool color groups. For example, yellow-green tones carry the warm and stimulating qualities of yellow while also including the effects of green, which are associated with nature and balance. Similarly, red-purple tones can integrate the dynamism and

stimulation of red with the sense of tranquility and depth of purple. This dual character allows intermediate colors to create more flexible, multi-layered, and context-sensitive effects on spatial perception. The majority of color research in the literature has focused on primary colors (Elliot, 2015), while the effects of intermediate colors on spatial perception and user attitudes have been studied less frequently. Table 2 evaluates the effects of intermediate colors and their use in residential spaces.

Table 2. Use of achromatic intermediate colors in residential spaces (Michele Clamp Art, 2025)

CROMATİC SECONDARY COLOS	PROPERTIES of COLOR	COLOR EFFECT	RESIDENTAL USE AREAS
5YR ORANGE 	Orange, a mixture of red and yellow, reflects the dynamism and stimulation of red and the warmth and liveliness of yellow.	It's a stimulating color with a medium-high wavelength. It has an uplifting effect, but heavy use can cause restlessness (Manav, 2007). It's not widely preferred by users and isn't considered suitable for work environments. (Kwallek et al., 1997).	Medium light value and medium/saturated colors can be used in dining rooms and living rooms.
5GY GREEN-YELLOW 	Warmth and stimulation of yellow + Balance and naturalness of green	Green-yellow, also known as warm green, contains both warm and cool colors. It has a euphoric effect (Ulusoy et al., 2020). It reflects the color of nature and is peaceful and soothing.	It can be used in living and dining rooms. Higher-value, lower-saturated colors can be used in bedrooms.
5BG BLUE-GREEN 	Coolness and serenity of blue + balance and peace, contentment and joy of green (Jonauskaite & Mohr, 2025)	It reminds one of clear seas and leaves a calming, peaceful and relaxing effect.	High value, low/medium colors can be used in studies, children's/master bedrooms.
5PB PURPLE-BLUE 	The depth and mysticism of purple + The serenity of blue, the color of the sky	Calming, peaceful, relaxing, dark tones can evoke gloom.	High value, low colors can be used in bedrooms, children's/baby rooms, High value, low/medium saturated tones can be used in living and sitting areas.
5RP RED-PURPLE 	The liveliness and stimulation of red + the creativity, serenity and nobility of purple (Adıgüzel&Kolancı)	It is a focusing, calming color. It provides balance because it contains both cold and warm colors. (Duyan & Ünver, 2022).	Its high-value, low/medium saturated colors can be used in parents' and children's rooms. They are also suitable for study and recreation rooms.

Neutral or achromatic colors (black, white, and gray) play a functional role in interior design, particularly in residential rooms, from both an aesthetic and a psychological perspective. The literature notes that white makes a space feel more spacious, bright, and hygienic, and is therefore widely preferred, especially in small-scale residential rooms (Manav, 2007). Gray tones contribute to a balanced and calm atmosphere, giving a space a timeless and neutral identity, although their intensive use can lead to a cold and monotonous perception (Kwallek et al., 1997). Black, as a powerful element of contrast, provides depth and emphasis, but excessive use can make a space feel constricting and oppressive (Dalke et al., 2004). In this context, the use of different values of neutral colors in residential rooms, when combined in a balanced way with other colors, can positively affect both spatial comfort and user perception.

Table 3. Use of White, Black and Gray Colors in Residential Spaces

	ACROMATİC PRIMARY COLOS	PROPERTIES of COLOR	COLOR EFFECT	RESIDENTAL USE AREAS
WHITE		Freshness, cleanliness, clarity, purity, neutrality, positively calming	It makes the space look spacious and increases the brightness. (Hemphill, 1996; Jonauskaite & Mohr, 2025)	It can be used in all areas of the home. Excessive use can have a stimulating effect, but it's best used in a specific setting with compatible materials.
GREY		Balance, neutrality, serenity, dullness, melancholy, formality. Negative low arousal	Gray has many values, from light to dark. It is a neutral color and is often associated with negative emotions. (Jonauskaite & Mohr, 2025).	Gray can sometimes create a good background on walls, providing a backdrop for furniture within the space. Therefore, it's a popular choice for living rooms.
BLACK		Power, seriousness, sophistication, fear, negative strong arousal	It evokes darkness, unrest, and is depressive (Hemphill, 1996) Jonauskaite & Mohr, 2025). It leaves a dramatic effect on the space.	It is not suitable for use in residential spaces where space is limited. Optionally, it can be used in small living and working spaces.

4. Conclusion and Recommendations

This study aimed to analyze the effects of color use in residential interiors on user psychology, physiology, and spatial perception from a multidimensional perspective, considering color components (hue, value, saturation) and spatial function. The primary contribution of this research is its demonstration of the necessity to examine color effects relationally with value and saturation components, rather than solely based on hue, and its integration of this three-way interaction into a systematic framework.

The evaluations revealed that, in addition to the relationship between color and emotion, color use in a space exhibits certain consistent patterns in the literature. The study's findings indicate that warm colors (red, orange, yellow) are suitable for spaces requiring social interaction and energy. Specifically, red's appetite-stimulating effect supports its use in dining areas, while yellow tones' cheerful and energizing properties support their use in social spaces (Elliot, 2015; Jonauskaite & Mohr, 2025). In contrast, cool colors like blue and green stand out for their calming and peaceful effects, making them more frequently preferred in rest, sleep, and work areas (Kaya & Epps, 2004). However, this study goes a step further by indicating that this generalization is not absolute. For example, as noted by Jonauskaite & Mohr (2025), a high-saturation red can create aggressive effects in workspaces, whereas a low-saturation of the same color, like pink, exhibits calming properties, clearly demonstrating the importance of components. This finding supports the idea that value and saturation can be more decisive in evaluating color effects than hue (Valdez & Mehrabian, 1994). The component-based evaluations align with the established view in the literature that low-saturation and high-value (light) colors make spaces appear more spacious and expansive (Küller et al., 2009; Yıldırım et al., 2011). Conversely, high-saturation colors are said to have negative effects, particularly in work, rest, and sleep areas (Al-Ayashi et al., 2016; Kaya & Crosby, 2006; Valdez & Mehrabian, 1994).

In conclusion, this study has developed a holistic and systematic color guide that encompasses color design criteria specific to residential spaces. Colors, which play a fundamental role in the perception of a space, stand out as decisive physical qualities that should be addressed within the context of the figure-ground relationship. Accordingly, the choice of which hue or which component (value/saturation) of that hue to use on walls should be planned to align with the desired elements of the space. The systematic guide, created as a reference, aims to provide applicable strategies based on scientific research, transforming color selection from a purely subjective preference into a conscious design process that optimizes a space's functional performance and user experience. Future research that empirically validates these findings and comparatively examines color perception in different cultural contexts will provide significant contributions to the literature.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Disclosure Information

The article was written by a single author. There is a conflict of interest with the Person(s) named.

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Timber-Reinforced Concrete Composite Construction System and Brock Commons Student Residence Example

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Abstract

A composite structure is a building made from a combination of materials, such as steel, concrete and timber. These systems offer a more efficient construction method by utilising the superior properties of different materials. This study explains the timber-concrete composite construction system and its advantages using the Brock Commons Student Residence project in Canada as an example, and reveals the reasons for its selection. The timber-concrete composite system was chosen for Brock Commons due to the need for rapid construction, the abundance of timber production in Canada, the limited space available for a construction site given the building's location, and its sustainability advantages. Consequently, the seventeen-storey dormitory building was completed within seventy days. The building is economical, sustainable, environmentally friendly, lightweight and earthquake-resistant. Due to its prefabricated elements, on-site traffic is also minimised. The building uses a laminated timber column and floor system with two reinforced concrete cores.

Keywords: *Composite material, Timber-concrete composite construction system, Metal fasteners, Laminated timber structural element.*

Ahşap-Betonarme Kompozit Yapım Sistemi ve Brock Commons Öğrenci Yurdu Örneği

Öz

Kompozit yapılar, yapı taşıyıcı sisteminde aynı anda betonarme, çelik ya da ahşap gibi farklı yapı elemanları birlikte kullanılarak inşa edilen yapılardır. Farklı malzemelerin görece üstün özelliklerinden faydalanılarak oluşturulan bu tür sistemler daha verimli bir yapım sistemi sunmaktadır. Bu çalışmada amaç Kanada' da yapılmış olan Brock Commons Öğrenci Yurdu projesi üzerinden betonarme-ahşap kompozit yapım sistemini ve avantajlarını açıklayıp tercih nedenlerini ortaya koymaktır. Yurt binasının kısa sürede inşa edilmesi gerekliliği, Kanada'daki ahşap üretiminin fazla olması, yapının konumu itibarıyla şantiye olarak yeterli alan sunamamış olması ve sürdürülebilirlik alanında sağladığı avantajlar da göz önüne alındığında Brock Commons binasında ahşap-beton kompozit yapım sistemi tercih edilmiştir. Sonuç olarak on yedi katlı yurt binası; iki adet betonarme çekirdekle birlikte lamine ahşap kolon ve döşeme sistemi kullanılarak yetmiş gün içerisinde ekonomik, sürdürülebilir, çevre dostu, hafif, deprem yüküne dayanıklı, içerdiği prefabrike elemanlar nedeniyle şantiye içi trafiği en aza indiren kompozit bir yapı olarak tamamlanmıştır.

Anahtar kelimeler: *Kompozit malzeme, Ahşap – beton kompozit yapım sistemi, Metal bağlantı elemanları, Lamine ahşap yapı elemanı.*

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1. Introduction

A composite structure refers to a building that employs a combination of structural materials—including reinforced concrete, steel, and timber—within a single supporting system. These materials can be used together on the same load-bearing elements or to form different elements within the same system. Mechanical interaction between hardened concrete and timber is achieved either through keyed recesses formed in the timber or by installing mechanical fasteners prior to casting the concrete (Ceccotti, 2002). The development of timber–concrete composite (TCC) systems began shortly after the First World War as a response to shortages of steel, prompting the search for alternatives to conventional reinforced concrete and steel construction (Auclair et al., 2023). Since the 1970s, interest in timber-concrete composite systems has increased, and it is evident that this system is used not only to reinforce existing wooden flooring but also in the construction of flooring for new buildings and bridges (Turrini & Piazza, 1983; Natterer et al., 1996).

Timber-concrete composite systems are a construction technique. The structural performance of the timber and concrete elements in this system largely depends on the composite behaviour characteristics. This type of composite system is particularly popular in the United States, Australia and Europe. Timber-concrete composite systems are used in the renovation of old timber-frame and masonry buildings, as well as in new constructions, such as buildings and bridges. It is formed by timber beams and concrete slabs and is used in the construction of structural elements such as walls, floors and roofs. Timber-concrete composite systems are not yet widely used in Turkey. This study demonstrates the potential applicability of this little-known system in Turkey, and forms the basis for adapting the timber-concrete composite construction system to local conditions.

1.1. The Combined Use of Timber and Concrete in Construction

Since early construction practices, the cross-sectional dimensions of structural timber have been increased through laminating techniques that rely on mechanical joints to form all-wood composite members. However, because these joints deform under load, full composite action cannot be achieved. The use of concrete and timber within a single composite cross-section can be viewed as a natural progression of this traditional approach. Unlike all-timber laminations, full composite action is attainable with the use of non-slip connectors, allowing both materials to contribute their strength and stiffness most effectively. Composite timber–concrete systems exhibit several notable characteristics:

- They are lighter than equivalent reinforced-concrete systems, as timber has a substantially lower density than concrete (Figure 1.a).
- When the two materials are effectively connected, their load-bearing capacity can be up to three times greater—and their flexural rigidity up to six times higher—than conventional timber floor systems (Figure 1. a-b).
- They achieve greater structural efficiency, measured as load carried per unit self-weight, compared with all-concrete systems. Although they may be less efficient than pure timber systems, they are typically more economical (Figure 1. a, b, c).
- They also perform well as shear walls, with the concrete layer contributing racking resistance and the timber ribs providing stiffness against out-of-plane buckling (Figure 1).

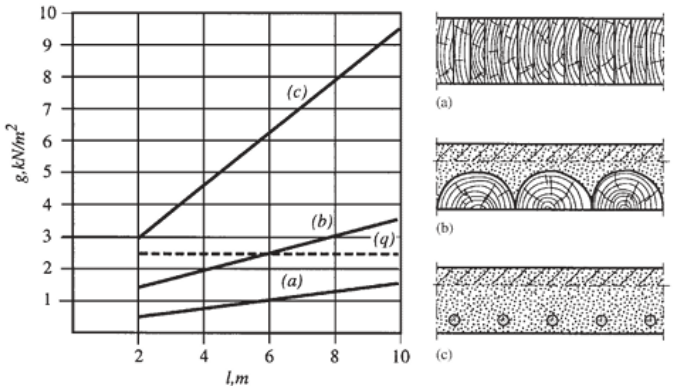


Figure 1. Relationship between floor self-weight g and span l for a service load of q=2,5 kN/m^2, comparing: (a) an all-timber section; (b) a concrete–timber composite section; and (c) an all-concrete section (Natterer et al., 1996)

Timber and concrete are used together in three different ways: as a building material, a building element, and a construction system.

1.1.1. Composite building material; Holzbeton

At first, Holzbeton was just an experimental product, and it was made from cement and wood shavings. It is then formed into blocks using a wooden frame and can be used in masonry structures (Figure 2). It is made from wood industry waste products. These are mixed with water and cement to create a concrete mixture, which is then shaped into blocks using chipboard moulds. The hollow blocks are filled with mortar on site prior to use. Thus, combining the ecological nature of wood and its heat-saving properties with the durability of concrete offers a new alternative building material. It has heat- and sound-absorbing properties. It is lightweight. It is also resistant to fire and weather conditions. Compared to traditional concrete blocks, it is a more sustainable building element. As it is a prefabricated element, it also speeds up the construction process (Şahin Diri, 2022).



Figure 2. As a building material; Holzbeton (Baustoffwissen, n.d.)

1.1.2. Composite structural element; Reinforced concrete–timber composite flooring

This composite system is used to construct structural elements such as walls, floors and roofs. It is formed using timber beams and concrete slabs (Figure 3. a). This makes use of the tensile strength of wood and the compressive strength of concrete, taking advantage of the best properties of both materials. The connection ensures complete composite behaviour between the wood and concrete. This mechanical connection can be achieved using nails, screws, or metal plates that are either embedded or notched in the wood (Halıcıoğlu & Yürekli, 2016) (Figure 3. b). Wood-concrete composite flooring is the most widely used structural element produced by this system. It is favoured over traditional timber-framed flooring due to its greater rigidity and reduced weight compared to reinforced concrete flooring (Şahin Diri, 2022). In timber–concrete composite systems, the concrete layer is generally a reinforced concrete slab, and the timber component can be composed of solid wood, glued laminated timber (glulam), structural composite lumber, cross-laminated timber (CLT), nail-laminated timber (NLT), or other engineered wood products (Auclair et al., 2023).

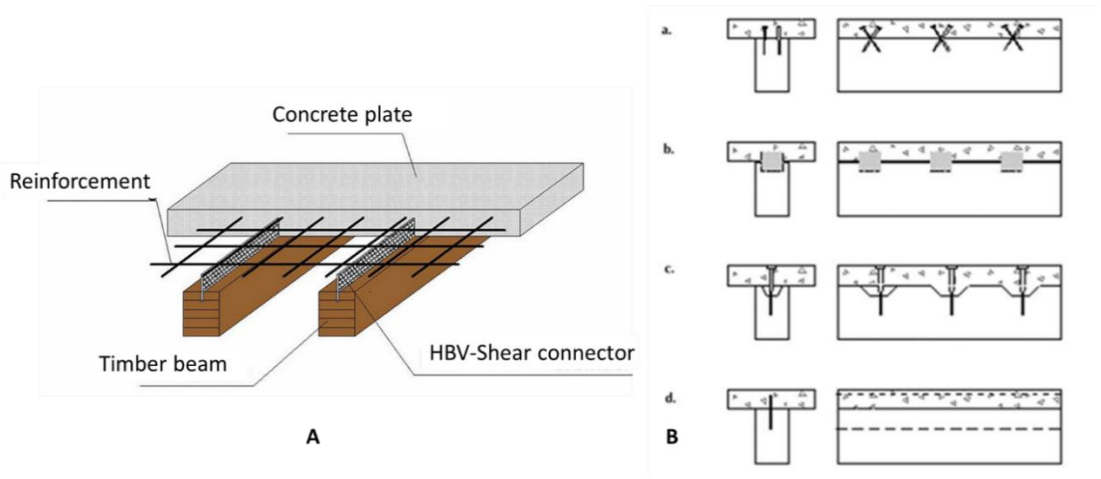


Figure 3. a) As a structural element; reinforced concrete slab with timber beams (Ticomtec, n.d.), **b)** Detailed connections for timber-beamed reinforced concrete slabs; a. Nail connection, b. Sheet metal connection, c. Chemical anchor connection, d. Bonded metal plate connection (Ceccotti, 2002)

1.1.3. Composite structure system: Timber-reinforced concrete composite structure

Timber-concrete composite building systems combine wood and concrete elements using various joint solutions. This composite behaviour improves the performance of the building's structure or facade. This method of building is used to make timber floors stronger and stiffer in existing buildings and in new constructions, especially in tall buildings and long structures. Upon achieving optimal interconnection between the two materials, the load-bearing capacity and bending rigidity of the composite structure are shown to exhibit a marked enhancement in comparison to that of a conventional timber floor system (Ceccotti, 2002). Timber-concrete composite systems can be a cost-effective solution for the construction of buildings with floors that have longer spans, since the mechanical properties of the two materials would be used efficiently (Auclair et al., 2023). Additionally, the extra mass of the concrete can enhance the acoustic performance when compared to that of a timber floor system alone. (Figure 4).

1.2. Timber- Reinforced Concrete Composite Construction

Advances in modern timber construction technologies have led to timber structures being widely used in public buildings, such as apartments, office buildings, schools, stadiums and conference centres (Figure 4). The structural elements of a building include its foundations, columns, beams and floors. We can list the combinations of load-bearing elements in timber and concrete composite buildings as follows:

- A timber-framed system resting on a reinforced concrete foundation.
- The use of timber floors within a reinforced concrete column-beam system or reinforced concrete floors in conjunction with a timber column-beam system.
- The use of a timber roof or façade system in a reinforced concrete structure.
- The construction of a timber-framed extension to a reinforced concrete structure is another example of how these systems can be used together.



Figure 4. Examples of timber-reinforced concrete composite construction systems: **a)** Eric Tweedale Stadium, Sydney, Dwp architects, 2021 (Dwp, n.d.), **b)** Ascent, Wisconsin, Korb & Associates Architects, 2022 (Thorntontomasetti, n.d.), **c)** Okanagan College Jim Pattison Centre of Excellence, Penticton-Canada, HDR /CEI Architect, 2010 (Fastepp, n.d.)

As the architects of Eric Tweedale Stadium (Figure 4. a); "Timber construction was fundamental to the project's sustainability objectives, illustrating that large buildings can be developed with low carbon output, low waste, and high energy efficiency. An eight-meter glulam roof cantilever provides a clean, expressive form recalling the site's historic forest. Alongside its low-carbon timber structure, the stadium employs east–west orientation, passive shading, rainwater harvesting, and photovoltaic and metering provisions to reduce energy and water demand." The stadium provides an active contribution to climate protection of around 109t CO2 emission (Archdaily, n.d.).

The Ascent project features nineteen mass-timber residential levels resting on a six-story cast-in-place, post-tensioned concrete podium that accommodates parking and retail spaces (Figure 4. b). The structural framework comprises glulam beams and columns supporting one-way CLT floor panels topped with gypcrete, with two reinforced-concrete cores providing lateral stability (Thorntontomasetti, n.d.). Post-tensioned transfer beams, designed in coordination with the pool and mechanical area depths, integrate the timber superstructure with the concrete garage below. This post-tensioned podium allows for reduced floor-to-floor heights while satisfying the structural and environmental requirements of a Midwestern parking facility.

The Okanagan College project exemplifies the implementation of Composite Concrete–Timber systems in the construction of gymnasium wall panels, integrating thermal insulation, embedded radiant heating conduits, and MEP rough-in components (Structurecraft, n.d.). The roofing system employs hybrid wood–steel truss assemblies. In alignment with the client's performance objectives, Fast + Epp engineered a series of innovative structural solutions (Figure 4.c). These advancements include the development of timber–concrete hybrid composite wall panels incorporating heating and cooling networks, the design of steel–timber hybrid trusses, and the extensive utilization of FSC-certified materials as well as lumber sourced from pine beetle–affected forests.

1.2.1. Advantages of using timber-concrete composite construction systems

- Structures made from reinforced timber composites are significantly lighter than concrete structures.
- Timber is a natural building material. Using timber instead of reinforced concrete in construction reduces the carbon footprint.
- Timber-Concrete Composite Construction Systems are more rigid and resistant to earthquakes and fire than traditional timber construction systems.

1.2.2. Disadvantages of the timber-concrete composite construction system

- High labour costs.
- Requiring excessive labour.
- Connectors increase the total construction cost.
- The necessity for special detail solutions.
- Structural behaviour differences offered by different materials, such as thermal resistance, thermal conductivity, seismic resistance and expansion coefficients.
- Special production requirements.

2. Material and Method

The wood-concrete composite system is widely used in the construction of buildings and bridges in many countries, but it is neither produced nor used in our country. The aim of this study is therefore to introduce the wood-concrete composite system, which is not yet in use in our country, and to present its potential applications in construction. To this end, the wood-concrete composite materials, elements and systems used in buildings were first described through a review of relevant literature and internet searches, followed by an examination of the example building's construction method.

- For this purpose, the structural design of Brock Commons in Canada, set to become the world's tallest wood-concrete composite structure upon completion, was analysed, and research was conducted into the design of the hybrid system by examining the functional sharing of the load-bearing system, as well as its cost, construction time, prefabrication advantages, weight, foundation dimensions, seismic behaviour and interface details between wood and concrete.
- Based on the results obtained, the advantages and disadvantages of using the wood-concrete composite system for multi-storey hybrid structures in general were identified, as were the reasons for preference related to these. An assessment was also made regarding what lessons could be learned for a possible 'concrete core + wooden floors' concept in Turkey.

3. Findings and Discussion

3.1. Brock Commons Student Residence Building

The advantages of the reinforced concrete-timber composite construction system in the design, implementation and usage stages are explained in this section using the example of Brock Commons Student Residence (Figure 5).

Project Location: Vancouver, B.C. **Project Type:** Dormitory Building **Size:** 15,115 m^2 **Completion:** 2017 **Structure Height:** 53 m **Structural System:** Mass Timber Hybrid, Point-Supported Mass Timber, Post-and-Beam **Project Materials:** Cross-Laminated Timber (CLT), Glue-Laminated Timber, Parallel Strand Lumber (PSL) **Design Team:** Acton Ostry Architects Inc. **Structural Engineer:** Fast + Epp **Tall Wood Advisor:** Architekten Hermann Kaufmann **Field Science:** GHL Consultants Ltd.	

Figure 5. Brock Commons Building, general information and outside view (Naturallywood, n.d.) Image (Brudder Productions, n.d.)

Brock Commons, a student residence in Vancouver, Canada, accommodates 400 students and, at 53 meters in height, was the world's tallest mass-timber building at the time of its completion. It

represents the university's eighth major timber project and serves as a significant driver of innovation for the regional timber industry (Hkarchitekten, n.d.). The site plan (Figure 6), typical floor plan and section (Figure 7) of the building are shown in the following figures. During the construction planning process, there was no available storage space, and a programme was implemented due to the site's physical constraints. Key advantages of the adopted structural system include the elimination of beams, the relatively low weight of the CLT panels, and the rapid erection facilitated by prefabrication. The primary drawback is the limited supply of CLT, as only one local manufacturer produces the panels; importing them from Europe was explored but deemed too costly due to shipping (Naturallywood, n.d.). The manufacture of the elements was therefore organised to coincide with the construction programme. Firstly, the reinforced concrete works were completely separated from the building. This enabled the assembly of the timber superstructure and installation of the building facade to begin once construction of the 18-storey reinforced concrete core was complete. The concrete works were scheduled for the winter months and the assembly of the timber superstructure was postponed until spring due to weather-related issues. To minimise water absorption on site, water-resistant coatings were applied to the timber elements at the production facilities. The roof structure was constructed from steel.



Figure 6. Building site plan (Naturallywood, n.d.)

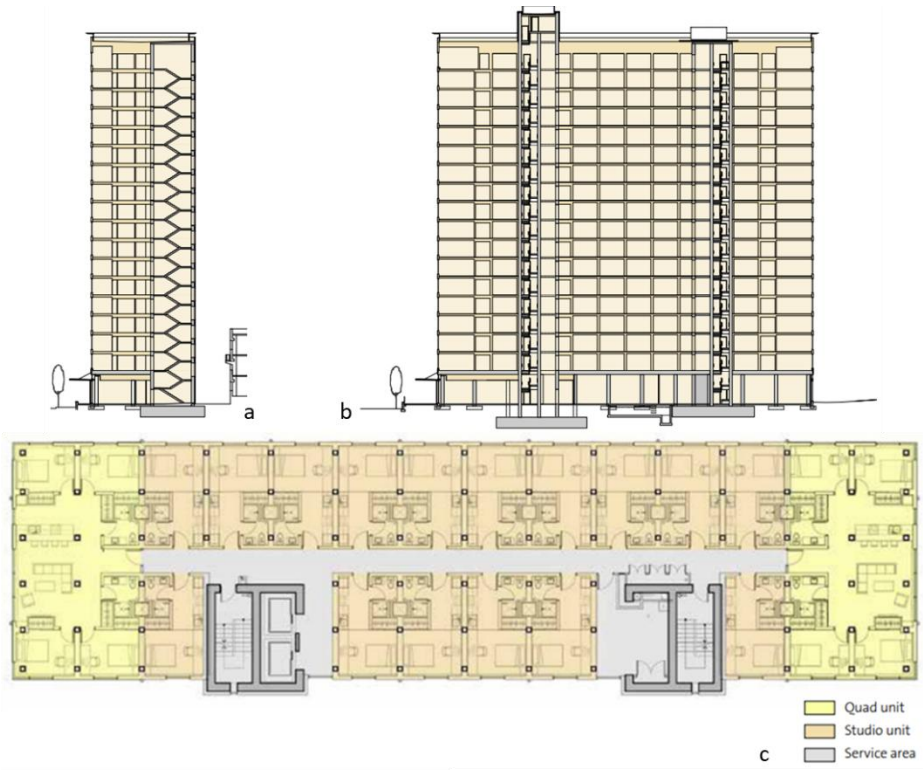


Figure 7. Brock Commons Building, typical floor plan and sections (Naturallywood, n.d.; Actonostry, n.d.)

With a typical inter-storey height of 2,8 m, the 18-storey building measures a total of 58,5 m to the top of the elevator parapet. Its floor area spans 840 m^2 (measuring 15 m × 56 m) across its 18 floors, housing 404 beds in single-bed studios and four-bedroom units. The building employs a hybrid structural system supported by 2,8 × 2,8 × 0,7 m reinforced-concrete spread footings (Figure 7 sections). Each core bears on a 1,5 m raft slab with soil anchors, and a 250 mm perimeter wall on a strip footing completes the foundation system. A concrete second floor functions as a transfer slab. The superstructure consists of a concrete podium and cores, mass-timber columns and floors, and a steel roof. The foundation system consists of 2,8 × 2,8 × 0,7 m reinforced concrete spread footings, supplemented by a 250 mm–thick perimeter wall supported on a 600 × 300 mm strip footing. Each core is founded on a 1,5 m–thick raft slab equipped with soil anchors capable of resisting 1,250 kN of tension (Naturallywood, n.d.). The concrete podium accommodates ground-floor amenities and provides the large spans and clear heights required for public areas at the first floor. The second-floor transfer slab carries gravity loads from the 17 stories above, decoupling the ground-floor structural grid from that of the timber structure. The 450 mm cast-in-place concrete cores (Figure 7 plan) ensure lateral stiffness and integrate vertical circulation, including stairwells and elevator shafts.

The primary framing system comprises mass-timber columns—Parallam in the highest-loaded regions and glulam elsewhere—together with a perimeter beam supporting the building envelope. Typical column dimensions are 265 × 265 mm and 265 × 215 mm on the upper levels, arranged within a 4 × 2,85 m structural bay (Connolly, Loss, Iqbal and Tannert, 2018). The main prefabricated elements include CLT floor panels, glulam columns, steel connectors, and the facade (Figure 8). These components are assembled atop a concrete base and stair cores. Cross-laminated timber (CLT) floor slabs rest on these columns; the five-layer panels provide a total thickness of 16,6 cm. The staggered two- and three-span CLT panels act biaxially, enabling a joist-free ceiling and facilitating rapid installation as well as straightforward integration of building services. Shear transfer between adjacent CLT panels is achieved using recessed three-layer plates, creating a continuous structural diaphragm (Hkarchitekten, n.d.). Horizontal loads from wind and seismic action are carried via steel straps from this diaphragm to the concrete core, while the timber columns transmit vertical loads to the reinforced-concrete ground-floor structure.

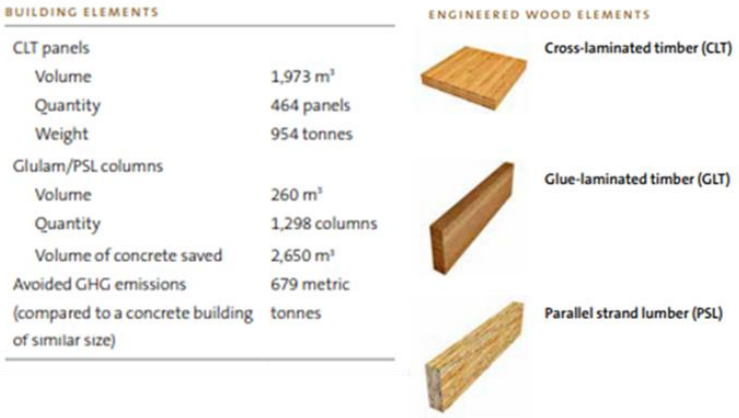


Figure 8. Materials used in the building (Naturallywood, n.d.)

The interior design prioritizes fire protection and acoustic separation. Encasing the timber columns and floor panels provides a two-hour fire-resistance rating (Figure 9). Internal demising walls are rated for two hours between suites and one hour between units and corridors.

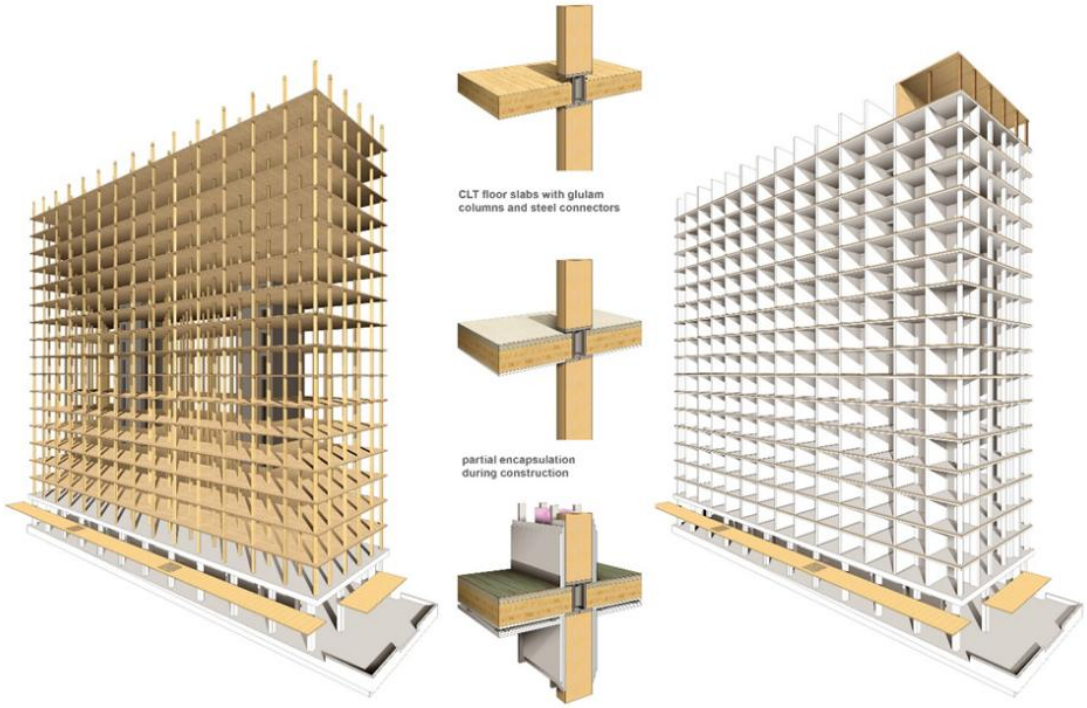


Figure 9. Brock Commons Building drawings and flooring details; most of the mass timber elements were wrapped in gypsum board, mainly to protect them from fire (Naturallywood, n.d.; Livinglabs, n.d.)

The Brock Commons structural system utilizes a hybrid configuration (Figure 10. a). The foundations, ground floor, and cores are constructed from cast-in-place, reinforced concrete, while a concrete second-floor slab serves as a transfer level between the concrete and timber elements, allowing the ground-floor structural grid to differ from that of the wood superstructure. Acoustical performance targets 52–54 STC (Sound Transmission Class) for floor assemblies and 50–62 STC for walls (Naturallywood, n.d.). To enhance sound absorption and minimize vibrations, a 40 mm concrete topping is added to the CLT panels to increase mass and stiffness, provide fire protection during construction, and an air cavity is incorporated within the ceiling assembly. Additionally, carpet tiles and resilient flooring are used to reduce impact noise (Figure 10. b). From the third to the eighteenth floor, gravity loads are supported by glulam (GLT) columns and CLT panels, with PSL columns employed in higher-load zones between floors 2 and 5 (Naturallywood, n.d.). Point connections between columns and floor slabs are realized using hollow structural steel assemblies.

Although the project utilizes only four standard panel sizes, most panels on a single floor are unique due to the arrangement of mechanical, plumbing, and electrical openings. The CLT panels are 169 mm thick and consist of five layers of dimensional lumber. Each floor's 29 panels are connected using a 140×25 mm plywood spline, fastened with nails or screws to adjoining panels (Naturallywood, n.d.). The panels were manufactured in four lengths: two 6 m panels and two 10 m panels at the cores, nineteen 8 m panels, and six 12 m panels (Figure 10. c–d). PSL columns are incorporated on floors 2 through 5 at the building's center to provide additional compressive strength.

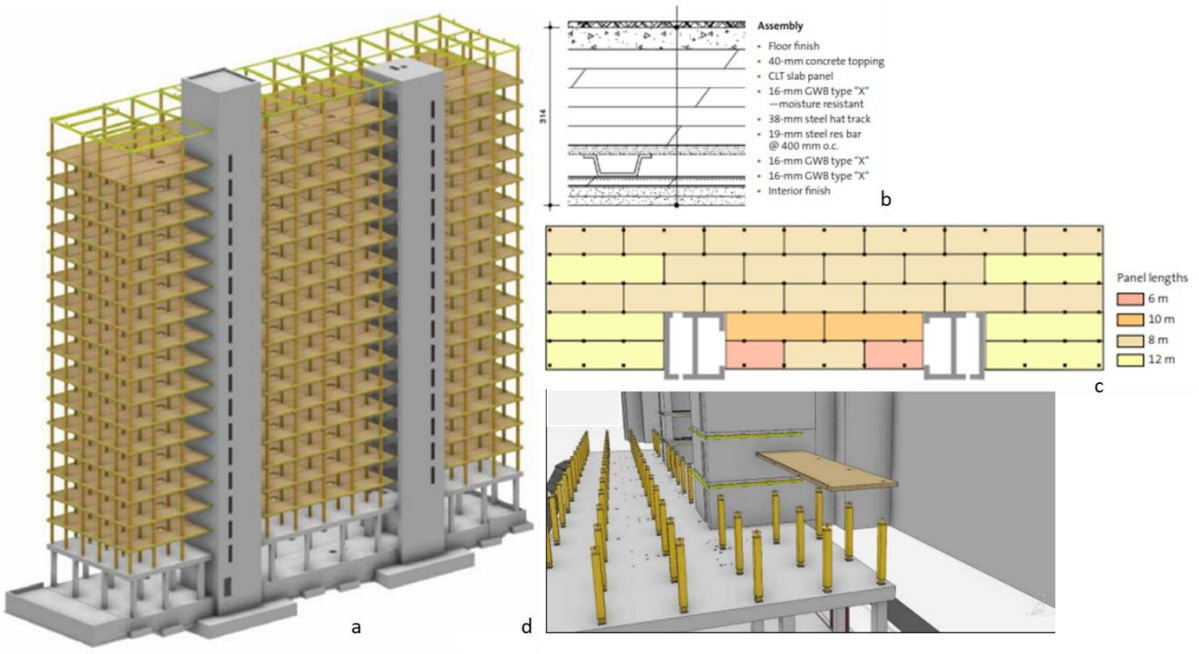


Figure 10. a) Hybrid structural system (Naturallywood, n.d.), **b)** Typical floor section detail (Naturallywood, n.d.), **c)** CLT panel plan (Naturallywood, n.d.), **d)** The connection of GLT columns-CLT floor panels and reinforced concrete core drawing (Naturallywood, n.d.)

Figure 11. a illustrates the connections between the reinforced concrete slab and the timber columns. Equally important is the interface between the CLT floor panels and the concrete core, which must transfer vertical shear while accommodating the differential settlement between the timber and concrete systems, estimated at approximately 50 mm. This was achieved using a steel ledger angle (203 × 152 × 13 LLH) welded to a 300 mm embedded plate cast into the core at 1,500 mm intervals, then fastened to the CLT panels (Naturallywood, n.d.). Adjacent CLT panels were connected along their edges using 140 × 25 mm plywood splines. A round hollow structural section is welded to steel plates embedded at both the top and bottom of each column and secured with threaded rods epoxied into the column. At the column bases, a smaller-diameter hollow section nests within the one above. The CLT panels rest atop the lower columns and are anchored to the steel plates with four threaded rods (Figure 11. b). Figure 11. c shows a cross-section of the rooms in the dormitory building. The building's prefabricated façade consists of 8 m–long steel-stud sections with integrated Windows (Figure 11. d). The cladding was replaced with high-pressure laminate panels made of 70% wood-based fibers, displaying a striped pattern of light and dark shades. Corner glazing softens the building's edges, while a metal cornice caps the structure (Naturallywood, n.d).

The building was erected extremely quickly, with two floors added each week; the superstructure was completed in only nine and a half weeks, ahead of schedule. The mass-timber superstructure is approximately 7,648 tons lighter than an equivalent concrete building, allowing for smaller and more economical foundations (Fast et al., 2016). However, in a high-seismic context like Vancouver, the reduced mass also lowers the structure's overturning resistance compared to concrete.

Wood is a sustainable and versatile building material. It stores carbon dioxide rather than emitting it, and continues to do so for the life of the structure and beyond when wood fibre is recycled or reclaimed. Using wood products instead of other materials in the building avoids the emission of more than 2,432 metric tons of carbon dioxide equivalent. The building was designed to achieve LEED Gold certification (Thinkwood, n.d.).

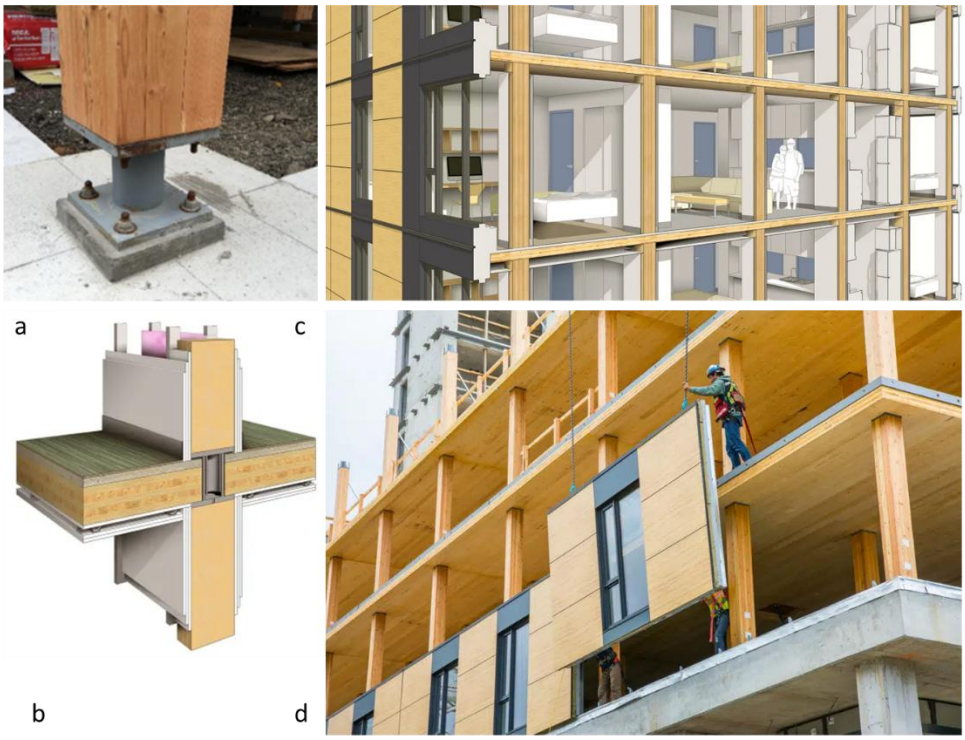


Figure 11. a) Column-to-slab connection (Connolly, et al., 2018), **b)** Steel connector detail at CLT panel floor-and-GLT column intersection (Architectmagazine, n.d.), **c)** Encapsulated mass timber structure (Actonostry, n.d.), **d)** Facade panel installation (Naturallywood, n.d.) Image (Law, K.K., n.d.)

3.2. The Advantages of Using Timber-Concrete Composite Systems in Construction

- The CLT panels used for the flooring are load-bearing in two directions and therefore do not require supporting beams.
- The reinforced concrete cores of the building provide lateral stability by moving in unison with the CLT floor panels. This also reduces seismic loads.
- Due to the adjustment of the panel size according to the maximum span that can be crossed in the plan, together with the timber column system and the design of the architectural project, the span has increased and the structural efficiency of the system has improved, while the total number of panels per floor has decreased.
- The reinforced concrete timber composite structure is lighter than a reinforced concrete structure.
- The use of timber in the flooring has improved the structure's acoustic properties.

3.3. The Disadvantages of Using Wood-Concrete Composite Systems in Construction

- The water absorption of timber materials in the structure must be taken into account, and installation must be carried out according to weather conditions. For this reason, timber manufacturing at the construction site took place during the spring months.
- As current standards in the western Canadian market could not meet the moment and deflection values in the two-way spread CLT panels, the panels were specially manufactured.

4. Conclusion and Suggestions

This study examined the Brock Commons Student Residence project, in which processed timber structural elements were favoured alongside reinforced concrete. The results obtained in the material comparison table (Table 1) lend support to the use of these elements.

Table 1. Evaluation table of construction materials according to selection criteria

	in-situ reinforced concrete	prefabricated reinforced concrete	natural wood	engineered wood	welded steel	bolted steel connection
accessibility to materials	6	5	2	3	5	5
ecology and sustainability	3	3	6	5	4	4
load applied to the structure	3	4	6	6	5	5
cost	6	5	2	3	4	4
construction period	2	5	3	4	3	4
effect on human health	3	3	6	5	4	4
construction site waste generation	3	6	6	6	5	6
sound transmission	4	4	6	6	2	2
thermal conductivity	5	5	6	6	1	1
fire resistance	6	6	1	1	3	3
seismic resistance	4	4	5	5	6	6
opening passed through	4	5	3	5	6	6
energy consumption during production	4	3	6	5	1	2
the service life of the material in the structure	3	3	5	5	6	6
Total	**56**	**61**	**63**	**65**	**55**	**58**

Note: This table compares material types according to the criteria that determine material selection. The most advantageous material is given a value of 6, and the most disadvantageous material is given a value of 1 (The data was obtained from a survey conducted among faculty members and construction industry workers).

Compared to traditional timber systems, timber-concrete composite systems offer greater advantages in terms of rigidity, acoustic performance, fire resistance and earthquake resistance. Wood is a natural building material. Using wood instead of reinforced concrete in construction reduces the amount of harmful gases released during concrete production and use, consequently reducing the carbon footprint. Compared to reinforced concrete systems, the reduced weight decreases the load on the foundation, thereby increasing earthquake resistance. Furthermore, wood's aesthetic appearance makes wood-concrete composite building systems more appealing from an architectural perspective.

This composite system, which combines timber and concrete, provides structural and environmental benefits compared to structures made of either wood or reinforced concrete alone. The Brock Commons building has also gained a lighter and stronger structure. Using wood has enabled a more ecological design. Furthermore, factory production of the timber elements meant that construction could be completed in just seven months. The timber-concrete composite system's versatility, as demonstrated by its use in both new buildings like Brock Commons and the reinforcement of old structures, enhances its appeal.

This study highlights the advantages of using reinforced concrete-timber composite systems in buildings. However, it also reveals that these applications require special detail solutions and detailed work plans. Efforts should be made to facilitate easier solutions and promote the use of these construction systems. Taking into account the native wood species in Turkey and earthquake regulations, a future study is proposed that will involve the design and numerical analysis of a similar hybrid system.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Disclosure Information

The article was written by a single author. There is no conflict of interest.

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Digitalisation of Quality Management Systems in Construction Industry: A Conceptual Exploration

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Abstract

Although Quality Management Systems (QMS) play a critical role in ensuring consistency, performance, and sustainability in construction projects, traditional practices often fall short in addressing the sector's rapidly digitalizing and highly fragmented nature. Quality 4.0 emphasizes the value of emerging technologies, yet existing interpretations remain broad and do not fully reflect the operational realities of construction. This study reinterprets Quality 4.0 principles from a construction-specific perspective and examines how digital tools can be systematically integrated into core quality functions. Using a structured review of current literature and sectoral practices, the research develops an adaptive framework that links technological capabilities with inspection, documentation, communication, and continuous improvement processes.The results show that effective digital integration requires rethinking quality workflows through complexity, uncertainty, and non-linear project dynamics. The proposed framework offers a targeted approach to modernizing QMS and enhancing transparency, decision-making, and overall project performance in construction.

Keywords: *Digitalisation, Quality management systems, QMS, Construction projects, Quality 4.0.*

İnşaat Endüstrisinde Kalite Yönetim Sistemlerinin Dijitalleşmesi: Kavramsal Bir Değerlendirme

Öz

Her ne kadar Kalite Yönetim Sistemleri (KYS), inşaat projelerinde tutarlılığın, performansın ve sürdürülebilirliğin sağlanmasında kritik bir rol oynasa da, geleneksel uygulamalar sektörün hızla dijitalleşen ve oldukça parçalı yapısını karşılamakta yetersiz kalmaktadır. Quality 4.0 yaklaşımı yeni teknolojilerin değerini vurgulasa da, mevcut yorumlar geniş kapsamlı olup inşaat sektörünün operasyonel gerçekliklerini tam olarak yansıtmamaktadır. Bu çalışma, Kalite 4.0 ilkelerini inşaat odaklı bir bakış açısıyla yeniden yorumlamakta ve dijital araçların temel kalite fonksiyonlarına nasıl sistematik şekilde entegre edilebileceğini incelemektedir. Güncel literatür ve sektörel uygulamaların yapılandırılmış bir değerlendirmesi üzerinden, teknolojik yetkinlikleri denetim, dokümantasyon, iletişim ve sürekli iyileştirme süreçleriyle ilişkilendiren uyarlanabilir bir çerçeve geliştirilmiştir. Bulgular, dijital entegrasyonun etkin olabilmesi için kalite iş akışlarının karmaşıklık, belirsizlik ve doğrusal olmayan proje dinamikleri ışığında yeniden düşünülmesi gerektiğini göstermektedir. Önerilen çerçeve, KYS'nin modernizasyonuna katkı sağlamakta ve şeffaflığı, karar alma süreçlerini ve genel proje performansını artırmayı amaçlamaktadır.

Anahtar kelimeler: *Dijitalleşme, Kalite yönetim sistemleri, KYS, İnşaat projeleri, Kalite 4.0.*

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1. Introduction

Although Quality Management Systems (QMS) play a critical role in ensuring consistency, performance, and sustainability in construction projects, their effectiveness often depends on proper implementation across all project phases (Rumane, 2017; Sui Pheng & Hui Hong, 2005). Traditional QMS, typically aligned with ISO 9001 standards, rely on planned procedures, documentation, inspections, and corrective–preventive actions to ensure compliance and continuous improvement (Hoonakker et al., 2010; Jraisat et al., 2016). Despite their importance, these systems frequently face practical challenges, including fragmented information flow, inconsistent documentation, delayed reporting, and limited traceability, which can undermine both quality control and overall project outcomes.

In recent years, the construction industry has been increasingly shaped by Industry 4.0, which integrates automation, data analytics, cloud computing, and smart sensing technologies into production and project management processes (Sawhney et al., 2020; PMI, 2021). Within this broader digital transformation, the concept of Quality 4.0 has emerged as a cross-industry paradigm that emphasizes enhanced connectivity, real-time data availability, integrated workflows, and evidence-based decision-making. Quality 4.0 provides a conceptual lens for understanding how digital technologies can reinforce traditional quality practices while introducing new capabilities such as predictive analytics and proactive monitoring (Marsden, 2019; Luo et al., 2022).

While Quality 4.0 is applicable across multiple sectors, the construction industry operationalizes this paradigm through domain-specific tools that embody its principles. Technologies such as Building Information Modeling (BIM), cloud-based document management systems, mobile inspection applications, Internet of Things (IoT) sensors, and digital dashboards exemplify how Quality 4.0 concepts are implemented in practice (Sacks et al., 2018; Sawhney et al., 2020; Araya-Santelices et al., 2025; Shaban et al., 2024; Ghosh & Karmakar, 2025). These tools support improved information consistency, traceability, collaboration, and decision-making, yet their deployment remains uneven across projects and organizations.

Despite growing attention, existing studies largely focus on individual technologies, specific project phases, or organizational contexts. There remains limited conceptual understanding of how commonly referenced digital technologies collectively align with core QMS activities in construction. Addressing this gap, the present study provides a conceptual exploration of digital QMS in construction, synthesizing literature on both traditional QMS functions and enabling technologies under the Quality 4.0 paradigm. By mapping digital tools to foundational quality processes, this work clarifies current developments in digitalized construction quality management and lays a foundation for future empirical and model-based research in this emerging field.

1.1. Challenges of Traditional QMS in Construction

Quality management in construction involves the structured processes and practices designed to ensure that project outcomes comply with standards, meet client requirements, and satisfy regulatory expectations (Rumane, 2017). Key components include planning, documentation, inspection, verification, corrective and preventive actions, and continuous improvement (Sui Pheng & Hui Hong, 2005; Hoonakker et al., 2010). Unlike manufacturing, construction projects are temporary, site-specific, and involve multiple stakeholders, leading to unique challenges such as variable site conditions, design–execution coordination issues, and diverse team interactions (Jraisat et al., 2016).

Traditional QMS in construction aim to ensure that projects meet client requirements, comply with standards, and satisfy regulatory expectations (Rumane, 2017). Core activities include planning, documentation, inspection, verification, corrective and preventive actions, and continuous improvement (Sui Pheng & Hui Hong, 2005; Hoonakker et al., 2010). However, the inherent characteristics of construction projects temporary nature, site-specific conditions, multiple stakeholders, and complex team interactions pose significant challenges for effective QMS implementation (Jraisat et al., 2016).

Key challenges of traditional QMS include;

- **Fragmented Information Flow:** Project information is often dispersed across teams and phases, leading to miscommunication, delays in decision-making, and inefficient coordination (Sacks et al., 2018; Sawhney et al., 2020; Marsden, 2019).
- **Inconsistent Documentation:** Reliance on manual record-keeping and paper-based processes increases the risk of errors, omissions, and duplication, undermining traceability and compliance (Ghosh & Karmakar, 2025; Araya-Santelices et al., 2025).
- **Delayed Reporting:** Slow feedback from inspections and quality checks often results in reactive rather than proactive quality control (PMI, 2021; Shaban et al., 2024).
- **Coordination Gaps:** Disconnects between design and execution teams can cause deviations from project specifications and design intent (Sui Pheng & Hui Hong, 2005; Sharma & Laishram, 2023).
- **Labor-Intensive Processes:** Traditional QMS heavily rely on human input for monitoring, verification, and reporting, which increases the potential for inefficiencies and oversight (Hoonakker et al., 2010; Luo et al., 2022).
- **Limited Real-Time Visibility:** Lack of immediate access to project data constrains timely interventions and evidence-based decision-making (Zaid et al., 2025; Marsden, 2019).

Organizational culture and predominantly reactive quality control practices further exacerbate these challenges (Sui Pheng & Hui Hong, 2005). Despite these limitations, traditional QMS remain foundational, establishing structured procedures for monitoring compliance and supporting incremental improvement throughout the project lifecycle (Rumane, 2017). Nevertheless, these inefficiencies highlight the need for digital solutions that enhance connectivity, traceability, and real-time decision-making in construction projects (Luo et al., 2022; Araya-Santelices et al., 2025).

1.2. From Industry 4.0 to Quality 4.0

The limitations of traditional QMS have coincided with broader technological transformations across industries. Industry 4.0, characterized by the integration of automation, digitalization, data analytics, cloud computing, and smart sensing, has reshaped production, management, and operational processes in multiple sectors (Sawhney et al., 2020; PMI, 2021). Within this context, **Quality 4.0** has emerged as a cross-industry paradigm that leverages these technologies to enhance quality management practices.

Quality 4.0 emphasizes real-time data availability, connected and integrated workflows, predictive analytics, and evidence-based decision-making (Marsden, 2019; Luo et al., 2022). It transforms traditional quality management from reactive and documentation-heavy approaches into proactive, data-driven, and digitally enabled processes (Sacks et al., 2018; Zaid et al., 2025). Key enabling technologies include cloud platforms, IoT sensors, data dashboards, digital collaboration tools, and advanced analytics systems, which collectively facilitate traceability, transparency, and timely interventions (Sharma & Laishram, 2023; Shaban et al., 2024; Ghosh & Karmakar, 2025).

By conceptualizing quality management in the context of Industry 4.0, Quality 4.0 provides a framework for integrating digital tools with core quality processes, improving consistency, performance, and adaptability. This paradigm is applicable across industries, offering insights into how organizations can overcome the challenges associated with traditional QMS, including fragmented information flow, limited traceability, delayed reporting, and reactive decision-making (Araya-Santelices et al., 2025; Marsden, 2019).

2. Material and Method

This study adopts a conceptual research design to examine how widely discussed digital technologies relate to core QMS functions in construction. The material for the study consists of academic journal articles, books and recognised industry reports addressing traditional QMS practices, Industry 4.0 and Quality 4.0 concepts, and digital technologies applied in construction project environments. Particular

attention was given to literature published over the last decade, as recent studies increasingly explore the intersection of digitalisation and construction quality management (Figure 1).

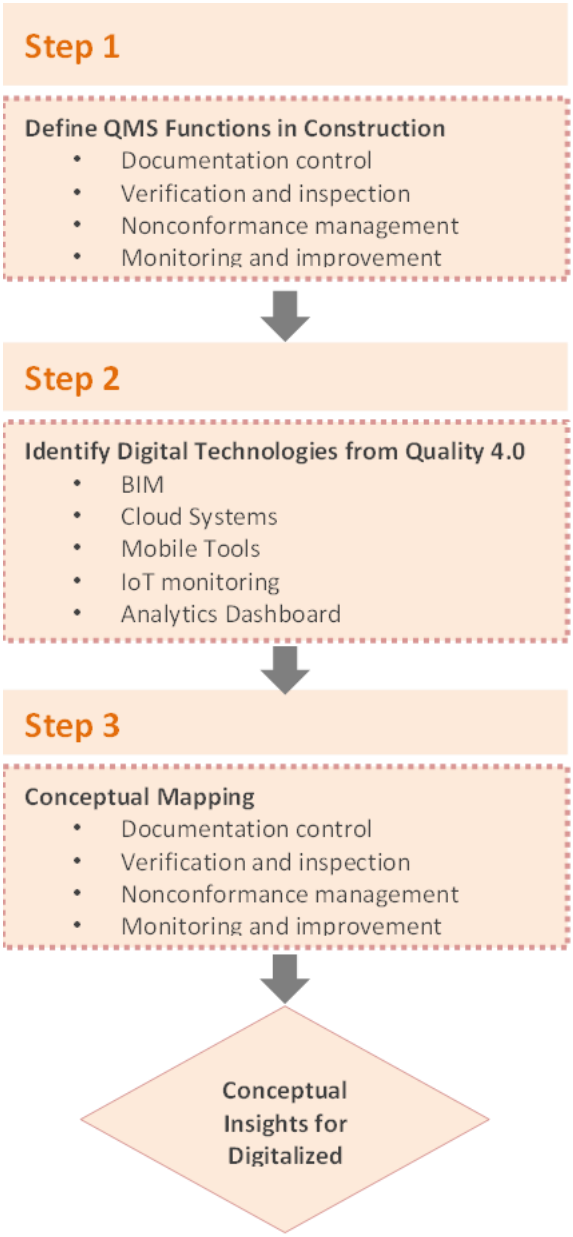


Figure1. Research workflow (Created by the author)

The technology categories considered in the analysis were informed by established Quality 4.0 literature, which identifies digital tools such as BIM, cloud-based document systems, digital collaboration platforms, mobile inspection applications, IoT monitoring devices and analytics dashboards as enablers of modern quality practices. These sources provided the conceptual basis for identifying relevant technologies in a systematic and literatüre grounded manner.

The methodological approach consisted of three steps as illustrated in Figure 1. First, core QMS functions in construction such as documentation control, design and work verification, inspection, nonconformance management, monitoring and continuous improvement were identified based on established QMS literature and ISO 9001 principles. Second, literature relating to digitalisation, Industry 4.0 and Quality 4.0 was reviewed to determine commonly cited technologies and their documented applications in construction quality contexts. Third, insights from these two bodies of literature were synthesised to conceptually map how selected digital technologies support or enhance fundamental QMS activities.

As a conceptual study, this approach does not involve empirical data collection or model development. Instead, it aims to consolidate fragmented knowledge and provide an integrated perspective that may guide future empirical investigations into digitalised quality management in construction projects.

3. Findings and Discussion

The findings of this study provide a conceptual synthesis of how commonly referenced digital technologies support core QMS functions in construction. Drawing on both traditional QMS principles (Sui Pheng & Hui Hong, 2005) and the enabling technologies highlighted in the Quality 4.0 domain (Marsden, 2019; Luo et al., 2022) , the analysis demonstrates that digitalisation enhances established quality activities by improving information consistency, coordination, traceability, and decision-making across project phases. To clarify these relationships, Table 1 presents a conceptual mapping between core QMS functions and Quality 4.0 enabled digital technologies. The table highlights six key QMS areas documentation control, design and work verification, inspection, nonconformance and CAPA management, monitoring and measurement, and continuous improvement and aligns each with relevant digital tools, including BIM, cloud-based document management, mobile inspection applications, IoT sensors, and analytics dashboards.

Table 1. Digital technologies commonly associated with Quality 4.0 and their relationship to core QMS functions in construction projects.

QMS Function	Traditional Purpose (ISO 9001 Context)	Supporting Digital Technologies (Quality 4.0 Enablers)	Key Contributions / Improvements
Documentation Control	Maintain, update, and trace project records	Cloud-based document management platforms	Real-time access
		BIM document modules	Version control
		Digital collaboration platforms	Improved traceability
			Reduced fragmentation
Design & Work Verification	Verify conformity of design and site work	BIM	Early clash detection
		BIM–GIS workflows	Improved design communication
		Model-based coordination tools	Enhanced consistency between design and site
Inspection & Site Quality Control	Conduct scheduled and unscheduled quality inspections	Mobile inspection apps	Faster reporting
		Field management platforms	Digital checklists
		Reality capture tools (photogrammetry, 360°)	Photo-enabled evidence
			Consistency in inspections
Nonconformance & CAPA Management	Identify, report, and resolve deviations	Digital issue-tracking systems	Faster identification
		Cloud-based NCR/CAPA workflows	Digital audit trail
		Mobile NCR reporting tools	Transparent corrective actions
Monitoring & Measurement	Collect and evaluate process or product data	• IoT monitoring devices	Real-time data
		Environmental sensors	Evidence-based decision making
		Analytics dashboards	Continuous monitoring
Performance Evaluation & Improvement	Evaluate quality performance and improve processes	Data analytics platforms	Trend analysis
		Integrated digital QMS	Feedback loops
		Lessons-learned systems	Supports continuous improvement

To make the conceptual contribution explicit, Table 1 does not merely list digital tools, but systematically maps Quality 4.0 enabled technologies to core QMS functions. This mapping clarifies how digitalisation operationally supports established quality management activities rather than

treating technologies as standalone innovations. By aligning each QMS function with specific digital enablers and their corresponding contributions, Table 1 provides an analytical lens for interpreting the role of Quality 4.0 in addressing key contributions.

In documentation control, as illustrated in Table 1, cloud-based platforms, BIM-enabled documentation modules, and digital collaboration tools mitigate longstanding challenges of fragmented or outdated records (Hoonakker et al., 2010). They enhance version control, provide real-time accessibility, and improve traceability, directly addressing weaknesses of traditional paper-based systems (Ghosh & Karmakar, 2025; Shaban et al., 2024).

For design and work verification Table 1 shows BIM and BIM-GIS workflows offer structured environments for model-based coordination and early discrepancy detection (Sacks et.al., 2018). These tools improve design interpretation, reduce errors during handover, and enhance alignment between design and site activities, contributing to lower rework and more reliable outcomes (Sharma & Laishram,2023).

Inspection and site quality control benefit from mobile inspection tools and reality-capture Technologies (Table 1). Digital checklists, photo evidence, and automated timestamps support more consistent, transparent, and timely inspections, resolving issues of delayed reporting and inconsistent field documentation (Marshdan, 2019).

In terms of nonconformance and CAPA management (Table 1) , digital issue-tracking systems and cloud-based NCR workflows enable faster identification, assignment, and resolution of deviations. They provide a clear audit trail and facilitate coordinated corrective actions, which are essential for effective QMS implementation (Gosh&Karmakar, 2025; Zaid et al., 2025).

For monitoring and measurement, IoT sensors, environmental monitoring devices, and dashboards provide real-time data, enabling evidence-based decision-making and proactive responses to quality deviations. This transition from reactive to data-driven monitoring exemplifies a major improvement over conventional practices (Luo et al., 2022).

Finally, digital tools contribute to continuous improvement by enabling data aggregation, trend analysis, and integration of lessons learned. Analytics dashboards and reporting platforms support monitoring long-term performance and establishing structured feedback loops, reinforcing ISO 9001 principles of learning and improvement (Rumane, 2017).

Overall, the conceptual mapping shows that digitalisation complements rather than replaces traditional QMS practices. It serves as an integrative framework that link traditional QMS with Quality 4.0 capabilities. Quality 4.0 technologies address persistent gaps such as fragmented documentation, limited visibility, and slow information flow while introducing new capabilities around connectivity, automation, and real-time data. Their effectiveness, however, depends on organisational readiness, interoperability, and alignment with established procedures, echoing broader observations in the literature on digital adoption challenges (Sharma & Laishram; PMI, 2021).

Although this conceptual synthesis provides valuable insights, it is subject to limitations. The study is based solely on published literature and does not include empirical data from construction projects, limiting assessment of practical implementation challenges. It also does not account for variations across project types, organisational structures, or levels of technological maturity. Future empirical research is needed to validate, refine, and contextualise the conceptual linkages presented here.

4. Conclusion and Suggestions

This study provided a conceptual exploration of the potential of Quality 4.0 technologies to enhance construction quality management by addressing the limitations inherent in traditional QMS. By mapping core quality management functions to digital tools including BIM, cloud-based document systems, mobile inspection applications, IoT sensors, and analytics dashboards the study offers a framework for understanding how digitalisation can support more integrated, data-driven approaches to quality assurance.

The analysis underscores that digital tools are not a replacement for established QMS procedures but serve to augment them. Their adoption can foster proactive monitoring, structured feedback loops, and continuous improvement processes, creating opportunities for organisations to move from reactive to anticipatory quality management. This shift has implications not only for compliance and performance but also for improving collaboration across project teams and enhancing accountability. Additionally, investigating the integration of emerging tools and analytics with existing quality practices can provide further insights into optimising digital quality management in construction projects.

While the conceptual framework establishes a foundation, practical implementation and organisational readiness remain critical factors in realizing the benefits of digitalised QMS. Future empirical research could build on this framework by examining real world project applications through case studies, surveys, or longitudinal analyses, focusing on how digital tools are integrated into existing QMS workflows. In particular, empirical studies may investigate technology adoption maturity, organisational capabilities, interoperability challenges, and the measurable impacts of Quality 4.0 enabled QMS on project performance, resource efficiency, and stakeholder engagement. Such research would further contextualise and validate the conceptual relationships identified in this study.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

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The article was written by a single author. There is no conflict of interest.

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The Effects of Plant Diversity in Urban Living Spaces on Human Health and Well-Being

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Abstract

The rapidly growing population and intense urbanization have reduced the quantity and quality of green spaces in cities, making urban ecosystems fragile. This situation highlights the strategic importance of plant diversity for both ecological functions and human health and well-being. Evidence in the literature increasingly shows that elements of plant diversity, such as species richness and the balance between native and exotic species, improve the quality of the biophysical environment and also affect indicators such as psychological recovery and stress reduction. The World Health Organization and current international scientific studies emphasize that positive health effects are related not only to the presence of green spaces but also to their diversity and ecological integrity. Studies conducted in Turkey reveal significant differences in plant diversity from city to city, depending on regional climate, socioeconomic structure, and landscape management practices. National findings on the relationship between diversity levels and health indicators show that areas rich in plant diversity are considered more aesthetic, safer, and more peaceful by users, and that time spent in such areas significantly improves psychological well-being and increases physical activity. In this study, a systematic review was conducted in accordance with the PRISMA framework to comprehensively evaluate the relationship between plant diversity and human health in major cities of Turkey, considering ecological, psychological, and socio-cultural components.

Keywords: *Plant diversity, Urban green spaces, Urban ecology, Public health, Psychological well-being.*

Kentsel Yaşam Alanlarında Bitki Çeşitliliğinin İnsan Sağlığı ve Refahı Üzerindeki Etkileri

Öz

Hızla artan nüfus ve yoğun kentleşme, şehirlerdeki yeşil alanların miktarını ve kalitesini azaltarak kentsel ekosistemleri kırılgan hale getirmiştir. Bu durum, bitki çeşitliliğinin hem ekolojik işlevler hem de insan sağlığı ve refahı için stratejik önemini vurgulamaktadır. Literatürdeki kanıtlar, tür zenginliği, yerli ve egzotik türler arasındaki denge gibi bitki çeşitliliği unsurlarının biyofiziksel çevrenin kalitesini iyileştirdiğini ve psikolojik iyileşme, stres azaltma gibi göstergeleri de etkilediğini giderek daha fazla göstermektedir. Dünya Sağlık Örgütü ve güncel uluslararası bilimsel çalışmalar, sağlığa olan olumlu etkilerin sadece yeşil alanların varlığıyla değil, özellikle çeşitlilik ve ekolojik bütünlük derecesiyle de ilişkili olduğunu vurgulamaktadır. Türkiye'de yapılan çalışmalar, bölgesel iklim, sosyoekonomik yapı ve peyzaj yönetim uygulamalarına bağlı olarak şehirden şehire bitki çeşitliliğinde büyük farklılıklar olduğunu ortaya koymaktadır. Çeşitlilik düzeyleri ile sağlık göstergeleri arasındaki ilişkiye ilişkin ulusal bulgular, bitki çeşitliliği açısından zengin alanların kullanıcılar tarafından daha estetik, daha güvenli ve daha huzurlu olarak değerlendirildiğini, bu tür alanlarda geçirilen zamanın psikolojik iyilik halini önemli ölçüde iyileştirdiğini ve fiziksel aktiviteyi artırdığını göstermektedir. Bu çalışmada, ekolojik, psikolojik ve sosyo-kültürel bileşenleri dikkate alarak, Türkiye'nin büyük şehirlerinde bitki çeşitliliği ile insan sağlığı arasındaki ilişkiyi kapsamlı bir şekilde değerlendirmek için PRISMA çerçevesine uygun olarak sistematik bir inceleme yapılmıştır.

Anahtar kelimeler: *Bitki çeşitliliği, Kentsel yeşil alanlar, Kentsel ekoloji, Halk sağlığı, Psikolojik iyilik hâli.*

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1. Introduction

The rapid urbanisation, intensive land use changes, fragmentation of natural habitats, and effects of climate change together increase the complexity of urban ecosystems. Because of these factors, this situation has crucially become one of great importance for conserving biological diversity and maintaining human health and well-being (Marselle, Bowler, et al., 2021; Marselle, Hartig, et al., 2021; Spotswood et al., 2025). As there is a continuing decrease in the physical and psychological contact with nature within city dwellers, the amplified problems will pertain to chronic stress, anxiety, depression, and social disconnection. According to WHO (2017), green space quality and diversity pertain to being one of the basic correlates of public health. In such a context, it is not only the quantity of urban green spaces which plays an important role, but also qualities consisting of plant diversity, habitat integrity, and balance between native and exotic species, which have been considered decisive factors affecting ecosystem functioning and human health (Wu et al., 2024).

Because it lies at the intersection of three phytogeographic regions and roughly a third of its more than 11,000 vascular plant species are endemic, the country of Türkiye has great potential for high urban plant diversity. Plant diversity, however, varies significantly at the regional scale despite this richness. For example, in Istanbul, although species lists are extensive, exotic species dominate, and Shannon diversity can vary more with the relative distribution of species rather than species abundance, as seen in places like Aşiyan Cemetery. In Aegean cities such as Izmir and Aydın, where the Mediterranean climate predominates, the numbers range from 30 to 70 species, with exotic shrub and tree species making up most of the plant composition. Although the warmtemperate climate conditions of Antalya allow the use of a wide array of ornamental plants, the underrepresentation of native maquis elements in the urban landscape keeps diversity below its potential.

Under continental climate conditions, despite having a more restricted plant palette, a considerable proportion of native and even endemic species still appear in the surroundings of cities like Ankara. However, the proportion of exotic and cultivated taxa is rather high in composing the urban landscape, especially in parks and road-side plantings (Çakmak & Aytaç 2018; Oğuz 2004). Thanks to its humid climate, the Black Sea Region is characterized by shrubs, broad-leaved forest species, and herbaceous flora that are almost evenly distributed within the city bounds of Samsun, Trabzon, and Rize, resulting in a higher Shannon index than other regions (Güneroğlu et al. 2018). In Eastern and Southeastern Anatolia, due to climatic limitations in cities like Erzurum and Gaziantep, the total number of woody species decreases in urban areas; however, dominance by adapted species keeps the Simpson index at relatively higher levels (Ögçe et al. 2022).

These regional differences suggest that plant diversity is related not only to climatic and floristic conditions, but also to the socio-economic structure of cities, their management and maintenance practices (Gozalo & Panadero, 2021a; 2021b). Shannon-Wiener, Simpson and Whittaker indices, the ratio between native and exotic species, phenological type distribution and stratification analyses are some of the commonly used metrics to assess urban plant diversity (Gülsoy & Özkan, 2008; Ögçe et al., 2022). According to the studies conducted in Turkey, 71 woody species were recorded in seven cities and more than 70% of the parks were established using exotic species (Ögçe et al., 2022). Campus-scale studies conducted at Düzce reveal that herbaceous plant diversity is important for both recreational experience and ecosystem functions (Yazlık et al., 2020).

A multidimensional network of mechanisms can explain the effects of urban diversity on human health: species richness and structural diversity increase thermal comfort, improve air quality, reduce symptoms of stress and depression, and strengthen social interaction (Hartig et al., 2014). A study conducted in Belgrade Forest of Istanbul reported that green spaces with high diversity levels showed significant correlations with well-being, energy levels, concentration, and physical activity. International meta-analyses also show that plant diversity provides stronger psychological restoration compared to monotonous landscapes (Marselle, Bowler et al., 2021; Hu et al., 2025).

For this purpose, monitoring plant diversity in cities from all bioclimatic regions of Turkey alongside health and well-being indicators is a strategic necessity for ecological design and public health policies. Subjective health perception, depression–anxiety scale, stress level, quality of life, social

connectedness, and physical activity measurements can be used as health indicators; diversity indicators can be analyzed using metrics such as species richness, Shannon–Simpson indices, Whittaker β-diversity, native/exotic ratio, and number of layers (Akpınar & Cankurt, 2015; cited in Bostancı, 2021). However, despite the growing body of international literature, integrated studies that simultaneously evaluate urban plant diversity patterns and health-related indicators across different bioclimatic regions of Turkey remain limited. In particular, there is a lack of comparative, multi-city assessments that link diversity metrics with psychological well-being and public health outcomes within a unified analytical framework. This study will investigate the effects that plant diversity in urban living spaces has on human health and well-being within a multidimensional framework, as well as make recommendations in a direction that aligns with ecological design principles.

2. Material and Method

2.1. Research Design

This systematic review aims to compile urban plant diversity studies conducted in major cities of each of the seven geographical regions of Turkey-Istanbul, Izmir, Antalya, Ankara, Samsun, Erzurum, Gaziantep-in line with the PRISMA 2020 statement-and scientific publications that have discussed the relationship of such studies with human health both nationally and internationally (Page et al., 2021; Marselle, Bowler et al., 2021; Marselle, Hartig et al., 2021). From this perspective, the research has a dual-axis design that includes ecological and health-based indicators:

Ecological axis in this research includes such indicators like: species richness (S), Shannon–Wiener and Simpson (1–D and D) indices of woody and herbaceous plant species in cities, native–exotic species ratio, habitat stratification, and structural diversity (Ögçe et al. 2022; Çakır & Tuğluer 2025), while the health axis considers all the aspects of human health and well-being including stress, depression, quality of life, physical activity level, and social interaction (WHO, 2017; Yıldızbaş et al., 2025). Thus, both of these axes have been intertwined with a view to assessing comprehensively the effects of patterns of plant diversity across various climate and urbanization profiles of Turkey on public health.

2.2. Data Sources and Literature Review

In this context, the systematic review searched for articles that had been published between the years 2000 and 2025, using Web of Science, Scopus, PubMed, ScienceDirect, SpringerLink, Taylor & Francis, Google Scholar, TR Dizin, and DergiPark. These databases were selected since they have high coverage on the different fields of urban ecology, landscape science, environmental psychology, and public health, according to Zhao et al. (2022) and Spotswood et al. (2025).

The searches were conducted using keywords in both English and Turkish. The English keywords included 'urban biodiversity', 'plant diversity', 'Shannon index', 'urban green space', 'human health', 'well-being', and 'ecosystem services'. The Turkish keywords were: 'kentsel bitki çeşitliliği' (urban plant diversity), 'biyoçeşitlilik' (biodiversity), 'kentsel yeşil alan' (urban green space), 'Shannon indeksi' (Shannon index), 'insan sağlığı' (human health) and 'psikolojik iyilik' (psychological well-being) (Shannon, 1948; Simpson, 1949; Gülsoy & Özkan, 2008; Ögçe et al., 2022). Search strings created with Boolean operators were designed according to international systematic review standards (Page et al., 2021).

2.3. Inclusion and Exclusion Criteria

The inclusion criteria were: date of publication between 2000 and 2025; published in a peerreviewed journal as original research or review/meta-analysis; measured plant diversity within urban or semi-urban green spaces; reported Shannon or Simpson indices; and presented results related to health and wellbeing indicators.

In the inclusion of studies sampled in Turkey, preference was given to research conducted in large cities such as Istanbul, Izmir, Ankara, Antalya, Samsun, Erzurum, and Gaziantep (Ögçe et al., 2022; Yazlık et al., 2020).

The studies that focused on natural forest ecosystems, those that assessed only the presence of green spaces without measurement of plant diversity, those that did not report health indicators, and those with methodological deficiencies were excluded.

2.4. Study Selection Process (PRISMA Flow)

The study selection process was conducted in accordance with the PRISMA 2020 framework and followed four sequential stages: identification, screening, eligibility assessment, and final inclusion of studies. Initially, a total of 2,246 records were identified through database searching, and 612 duplicate records were removed. The remaining 1,634 studies were screened based on their titles and abstracts, resulting in the exclusion of 1,128 studies that did not simultaneously address plant diversity and health-related outcomes. Subsequently, 506 full-text articles were assessed for eligibility, and studies that did not meet the predefined inclusion criteria were excluded. As a result, 78 studies were included in the final qualitative synthesis, comprising 32 international studies, 26 studies from Europe and the United States, and 20 field-based studies conducted in Turkey (Page et al., 2021; Ögçe et al., 2022; Çakır & Tuğluer, 2025).

2.5. Data Extraction Process

A data extraction form was applied to each study in a systematic manner. The metric for plant diversity included species richness, Shannon–Wiener (H’), Simpson (1–D), the ratio of native-exotic species, stratification level, deciduous–evergreen balance, and seasonal tissue diversity (Güneroğlu et al., 2018; Ögçe et al., 2022).

Human health indicators such as psychological stress, depression, and anxiety scales (PSS, DASS, WHO-5), quality of life (WHOQOL), physical activity level, and social interaction scores were assessed in various studies (Yıldızbaş et al., 2025; Hu et al., 2025).

Sample area type, climate class, population density and land-use pattern were some of the significant information that was coded regarding urban and regional information (Söğüt, 2000; Niray, 2021).

2.6. Data Analysis and Synthesis Approach

A quantitative meta-analysis was not undertaken, due to methodological diversity among the studies; instead, a three-stage narrative synthesis method was applied. In the first stage, the studies had thematically been divided into categories such as "plant diversity-psychological health," "plant diversity-physical health," and "plant diversity-social well-being" (Marselle, Bowler et al., 2021; Spotswood et al., 2025).

In the second step, plant diversity values in the seven regions' largest cities were compared, and it was confirmed that the H’ values of the coastal cities were significantly higher than in inland and arid regions (Ögçe et al., 2022; Çakır & Tuğluer, 2025).

At the final stage, studies were assessed on the level of evidence concerning the sample size, the quality of the method applied, and the verifiability of the health indicators.

2.7. Ethical Considerations

This study is based on scientific literature published in journals and does not need any ethical committee approval. Sources used within this paper are cited by academic rules, with the full list presented in the references section.

3. Findings and Discussion

Table 1 synthesizes the main results derived from the reviewed literature by summarizing regional plant diversity patterns, associated ecological characteristics, and their implications for human health and well-being in major Turkish cities. The findings highlight a pronounced spatial gradient in plant diversity, strong contrasts between coastal and inland settlements, and consistent links between biodiversity levels and psychological, physical, and environmental health indicators.

Table 1. Summary of major findings on plant diversity patterns and health outcomes in large Turkish cities.

Theme	Regional Pattern	Key Findings	Health Implications	Main References
Plant diversity gradient	Coastal > Inland > Eastern regions	Higher Shannon index values in coastal cities; limited species richness in Ankara and Erzurum	Weakened ecosystem services in inland regions	Ögçe et al., 2022; Güneroğlu et al., 2018
Native–exotic species balance	Exotic species > native species in metropolitan areas	60–70% of park vegetation is dominated by exotic species	Increased allergen load and habitat degradation	Hatipoğlu & Ekren, 2022; Ögçe et al., 2022
Habitat stratification	Black Sea and Mediterranean > inland regions	Multilayered vegetation structure is stronger in coastal cities	Enhanced restorative environment perception	Yazlık et al., 2020; Hartig et al., 2014
Psychological health	Higher diversity = improved well-being	Reduced cortisol levels and increased attention	Lower risk of depression and stress	Hu et al., 2025; Yıldızbaş et al., 2025
Physical activity	Activity increases with increasing diversity	Higher park usage rates	Reduced obesity and non-communicable disease (NCD) risk	Akpınar & Cankurt, 2015; Marselle, Bowler et al., 2021
Ecosystem services	Broadleaf species dominant in coastal regions	Heat mitigation and particulate matter (PM) removal	Improved thermal comfort	WHO, 2017; Kabisch et al., 2017
Overall conclusion	Coastal cities are more advantageous	Plant diversity should be a primary planning criterion	Direct contribution to public health	Wu et al., 2024; Spotswood et al., 2025

3.1. Plant Diversity Patterns in the Major Cities of Türkiye

Based on literature findings from major cities representing Turkey's seven geographical regions, plant diversity follows a distinct spatial gradient across regions. Table 2 summarises the main findings regarding spatial patterns of plant diversity and their associations with physical, psychological and social health outcomes in major urban centres across Turkey. The temperate climate conditions in coastal cities (Istanbul, Izmir, Antalya, Samsun) increase habitat heterogeneity, which facilitates high distribution, especially for broad-leaved species, thus contributing to Shannon diversity values that range between 2.3 and 3.2 (Ögçe et al., 2022; Kuşak et al., 2022). Contrarily, in the cities of Central Anatolia and Eastern Anatolia (Ankara, Erzurum), where the dominant climate is continental, the species richness is more limited; the number of woody taxa is decreasing, but the Simpson index is relatively balanced due to the relative dominance of selected coniferous species (Güneroğlu et al., 2018). This situation shows that evaluating plant diversity may not be based only on the number of species but also on structural balances based on the relative abundance of species (Wu et al., 2024).

Table 2. Summary of main findings on plant diversity patterns and health outcomes in major Turkish cities (Ögçe et al., 2022; Kuşak et al., 2022)

Region	City	Climate	Diversity Level	Dominant Structure	Health Impacts
Marmara	İstanbul	Transitional	Medium	Exotic-dominated	Moderate
Aegean	İzmir	Mediterranean	Medium–High	Mixed shrubs & trees	High
Mediterranean	Antalya	Warm–humid	Medium–High	Ornamentals	High
Black Sea	Samsun	Humid	High	Native broadleaf trees	Very High
Central Anatolia	Ankara	Continental	Low–Medium	Conifers	Limited
Eastern Anatolia	Erzurum	Cold continental	Low	Sparse woody taxa	Low
Southeastern Anatolia	Gaziantep	Hot–dry	Low–Medium	Xerophytic species	Moderate

3.2. Native–Exotic Species Balance and Ecological Consequences

It is indicated that exotic species usage is very high, especially in big metropolitan areas (Istanbul, Izmir, Antalya), and that 60–70% of parks have a composition dominated by exotic species (Ögçe et al., 2022). Even though exotic species have several advantages, like enhancing landscape aesthetics and fast adaptation, they are reported to carry ecological and public health risks by weakening pollination networks, reducing interaction with native fauna, and increasing allergen load (Hatipoğlu & Ekren,

2022). On the other hand, higher proportions of native taxa, as seen in Black Sea cities, result in positive outcomes with regard to both air quality regulation and the continuity of ecosystem functions (Güneroğlu et al., 2018). These findings point to a need within Turkey for a hybrid approach in urban plant diversity planning that preserves the native species (Marselle, Bowler et al., 2021).

3.3. Habitat Stratification and Landscape Integrity

Habitat stratification, being the balance between tree-shrub-herbaceous layers, is one of the most important components influencing ecosystem services and differs substantially in the cities studied in Turkey.

It has been reported that shrub and herbaceous layers are stronger in Black Sea and Mediterranean cities, while stratification is weak and monocultural landscape patterns are dominant in Central and Eastern Anatolia (Ögçe et al., 2022; Yazlık et al., 2020). The structural diversity is considered one of the basic spatial elements which enhance psychological well-being, especially because of its impact on visual complexity and restorative experience (Hartig et al., 2014).

3.4. The Relationship Between Plant Diversity and Psychological Health

Findings from Turkish and international literature suggest that areas with high plant diversity can substantially reduce stress, improve mood and promote mental restoration. In clinical studies, even short visits to green spaces with high plant diversity have been found to reduce cortisol levels and improve mood (Hu et al., 2025). In the Belgrade Forest of Istanbul, a study revealed statistically significant improvements in energy, attention, physical activeness and overall well-being for the subjects exposed to high plant diversity (Yıldızbaş et al., 2025). The studies confirm that plant diversity plays a decisive role not only in physical health but also in cognitive and emotional health (Spotswood et al., 2025).

3.5 Plant Diversity, Physical Activity, and Social Health

Increasing the diversity of green spaces raises the motivation of individuals to use open spaces and thus provides higher physical activity levels for them. As revealed by the studies conducted in Turkey, parks with diverse plant species are perceived as more attractive, safe, and comfortable by users; visit times are also longer in areas with high species diversity (Akpınar & Cankurt, 2015; Yazlık et al., 2020). As stated by the international meta-analyses, not only does high landscape diversity increase the frequencies of walking and recreational uses but it also has positive effects on social interaction, community cohesion, and spatial belonging (Marselle, Bowler et al., 2021; Marselle, Hartig et al., 2021). These results support the indirect effects of ecological diversity on social health.

3.6 Ecosystem Services and Their Impact on Public Health

Plant diversity has a direct impact on public health through ecosystem services of air quality regulation, PM2.5 retention capacity, shading, heat island effect, and water cycle regulation, particularly in urban ecosystems. As diversity increases, the diversification of functional characteristics shows that there is a marked increase in heat reduction capacity and urban cooling efficiency (WHO, 2017). It has also been indicated that findings such as high diversity of leafy species, especially in Samsun, Istanbul, and Antalya in Turkish cities, are a positive aspect in which one can consider the heat island effect (Ögçe et al., 2022). Another reason that plant diversity is a critical variable for public health policies is the multi-layered impact on ecosystem services.

Indeed, when all the findings are considered in combination, it is obvious that there is a big variation in the urban plant diversity of Turkey, depending on geographical conditions, climatic features, planning perspective, and socio-economic characteristics. This is manifested in Tables 1 and 2. Therefore, plant diversity affects human health and well-being directly and indirectly. While higher plant diversity in coastal cities contributes to more positive psychological and social health outcomes, lower diversity in inland areas is related to the weakening of ecosystem services and higher health risks (Marselle, Bowler et al., 2021; Marselle, Hartig et al., 2021; Ögce et al., 2022). This situation urgently requires an approach to plant diversity systematically in urban planning in Turkey.

When compared with international research results, the overall trends in Turkey show a high degree of similarity with regard to results relating to urban areas in Europe, North America and East Asia, in terms of the correlation between high plant diversity and ecosystem services, and high PS (Hartig et al., 2014; Marselle, Bowler et al., 2021; Wu et al., 2024).

However, there is a fundamental difference in terms of the level of diversity loss and its underlying causes. While international papers tend to highlight urban densification and land-use intensity as major limiting factors, it is clear that management patterns, the large-scale use of exotic species, and the lack of integration of native flora into urban planning have a more decisive influence on diversity in the Turkish context.

Furthermore, compared to cities in Western Europe, where native species are increasingly prioritised through biodiversity-focused plans, Turkish cities exhibit greater dominance of exotic taxa for ornamental purposes. This may partially explain the lower resilience reported in certain regions (Marselle, Hartig et al., 2021; WHO, 2017).

4. Conclusion and Suggestions

This study demonstrates that plant diversity in major cities across different geographical regions of Turkey is a key determinant of both ecological quality and human health and well-being. The limited use of native species in urban green spaces, together with the dominance of exotic species, not only weakens ecosystem resilience but also poses public health risks in terms of allergen load, maintenance costs, and species continuity. Therefore, urban landscape planning should prioritise the use of native and ecologically compatible species, selecting them not solely based on aesthetic criteria but also on ecological performance and health-related considerations.

In this context, it is recommended that municipalities and local authorities integrate native species quotas and ecological suitability criteria into urban planting guidelines, tender specifications, and landscape design standards. In addition, the regular monitoring of plant diversity using indices such as Shannon–Wiener and Simpson, together with species richness, provides an objective and traceable tool for evaluating the quality of urban green infrastructure. Integrating these diversity metrics into municipal green space management and reporting systems would enable evidence-based monitoring of urban ecosystems over time.

Moreover, the planning of multilayered landscapes with tree–shrub–grass stratification enhances health-related ecosystem services, including thermal comfort, aesthetic perception, and psychological restoration. For future research, combining plant diversity indicators with validated health assessment tools (e.g. WHO-5, DASS, PSS) and developing region-specific landscape policies aligned with climate sensitivity should be considered priority actions to support sustainable urban health strategies.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Disclosure Information

The article was written by a single author. There is no conflict of interest.

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Farklı Yetiştirme Ortamlarının Datça Hurması (*Phoenix theophrasti-Phoenix theophrasti* subsp. *golkoy*) Fidanlarının Büyüme Özelliklerine Etkileri

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Öz

Bu çalışma; Phoenix theophrasti taksonlarının büyüme özellikleri üzerinde farklı yetiştirme ortamlarının etkisini belirlemek amacıyla gerçekleştirilmiştir. Bu amaçla Antalya İli, Kumluca İlçesi, Karaöz sınırları içerisinde doğal olarak yetişmekte olan P. theophrasti türü ile Muğla İli, Bodrum İlçesi, Göltürkbükü Beldesi sınırları içerisinde doğal olarak yayılış gösteren P. theophrasti subsp. golkoy tohumları 3 farklı yetiştirme ortamı içeren saksılara ekilmiştir. Deneme de torf (T), perlit (P), tınlı toprak (TT), kum (K) ve yanmış çiftlik gübresi (YÇG) farklı oranlarda karıştırılarak üç farklı yetiştirme ortamı hazırlanmıştır. Deneme süresince farklı yetiştirme ortamlarındaki gelişimi değerlendirmek amacıyla bitki yaprak sayısı, yaprak boyu ve yaprak eni ölçülmüştür. Çalışma sırasında sınırlı ve sabit bir gübreleme programı kullanılmıştır. Sonuçlar hem takson hem de yetiştirme ortamı açısından büyüme özelliklerinde önemli farklar olduğunu göstermiştir. Büyüme özellikleri açısından en iyi sonuçlar TT+YÇG+K yetiştirme ortamında görülmüştür. Ayrıca büyüme özellikleri açısından P. theophrasti (Karaöz/Kumluca)'nin önemli farkla yüksek değerler aldığı saptanmıştır.

Anahtar kelimeler: *Datça hurması, Phoenix theophrasti, Yetiştirme ortamı ve büyüme.*

Effects of Different Growing Media on the Growth Characteristics of Datça Palm (*Phoenix theophrasti-Phoenix theophrasti* subsp. *golkoy*) Seedlings

Abstract

This study was conducted to determine the effect of different cultivation environments on the growth characteristics of Phoenix theophrasti taxa. For this purpose, seeds of P. theophrasti, which grows naturally within the boundaries of Karaöz, Kumluca District, Antalya Province, and P. theophrasti subsp. golkoy, which grows naturally within the boundaries of Göltürkbükü Municipality, Bodrum District, Muğla Province, were planted in pots containing three different growing media. In the experiment, three different growing media were prepared by mixing peat (T), perlite (P), loamy soil (TT), sand (K), and burnt farmyard manure (YÇG) in different proportions. During the experiment, the number of plant leaves, leaf length, and leaf width were measured to evaluate the development in different growing media. A limited and fixed fertilization program was used during the study. The results showed significant differences in growth characteristics in terms of both taxon and growing medium. The best results in terms of growth characteristics were observed in the TT+YÇG+K growing medium. In addition, it was determined that P. theophrasti (Karaöz/Kumluca) had significantly higher values in terms of growth characteristics.

Keywords: *Phoenix theophrasti, Datça Palm, Growing media and growth.*

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1. Giriş

Doğal peyzaj düzenlemelerinin ekolojik olarak sürdürülebilir ve doğayı onarıcı özellikleri nedeniyle giderek daha fazla tercih edilmesi, peyzaj tasarımlarında yeni yerel türlerin yer almasının önemini daha da arttırmaktadır (Durak & Karagüzel, 2022). Bitkisel tasarım uygulamalarında yabancı yurtlu türlerin istilacı özellikleri ve bunların olumsuz etkileri de doğal türlerin daha cazip hale gelmesine olanak sağlayarak tercih edilebilirliğini arttırmaktadır. Türkiye, sahip olduğu zengin doğal bitki genetik kaynaklarıyla bu açıdan dünyanın en avantajlı ülkelerinden biridir. Gelişen ve hızla değişen dünyada süs bitkileri sektörü, kullanılan türler ve kültivarlar açısından hızlı bir dönüşüm göstermekte ve yeni türlere olan gereksinim artmaktadır. Bu nedenle, peyzaj tasarımlarında doğru ve kaliteli bitki türlerinin seçilmesi ile bu bitkilerin üretiminde güncel üretim tekniklerinin kullanılması zorunlu hale gelmiştir. Ayrıca, Türkiye'de süs bitkileri yetiştiriciliğinin artan önemi dikkate alındığında, pazar talebini karşılamak ve çeşitliliği artırmak amacıyla yeni tür ve çeşitlerin araştırılması ve sektöre kazandırılması gerekmektedir (Selim & Durak, 2025).

Genellikle tropik kuşağın özgün bitkileri olan ve bazı türleri subtropik bölgelerde de yetiştirilen palmiyelerin çok çeşitli cinsleri ve 1000'den fazla türü bulunmaktadır (Pamay, 1992). Palmiye türleri dekoratif görüntüsüyle ülkemizin kıyı şeridinde tercih edilmektedir. *Phoenix theophrasti* Yunanistan'da Girit Adası'nda ve Türkiye'de Muğla ve Antalya illerinde doğal olarak yayılım göstermektedir. *P. theophrasti* subsp. *golkoy* taksonu ise Muğla ilinde doğal yayılım göstermekte olup bir alt tür sayılmaktadır (Boydak & Barrow, 1995; Esener, 1999). Türkiye'nin doğal palmiye türlerinden olan *P. theophrasti* ve bir alt tür olan *P.theophrasti* subsp. *golkoy* haricinde yetiştirilen diğer tüm palmiyeler egzotiktir (Hazır & Büyüköztürk, 2013). 10-15 m boy ve geniş bir tepe yapısına sahip *P. theophrasti*'nin tüysü yapraklarının uzunluğu 3-5 m'yi bulmaktadır. İyi bir kıyı ve alle ağcı olan bu tür Akdeniz iklim kuşağında, korunaklı vadi içlerinde, sıcak ve güneşli yerlerde, deniz kıyısında, derin ve nemli, süzek ve hafif topraklar üzerinde iyi gelişim göstermektedir (Pamay, 1992).

Yabancı yurtlu palmiyelerin ithalatı palmiye kırmızı böceğinin (*Rhynchophorus ferrugineus*) yanlışlıkla ülkeye girmesine neden olmuştur ve sonrasında birçok ülkede palmiye ithalatı yasaklanmıştır (Hazır & Büyüköztürk, 2013). 2005 yılında Mersin ilindeki hurma (Phoenix dactylifera) ağaçlarında bu zararlıya rastlanmıştır (Karut & Kazak, 2005). Adana kentinde peyzaj alanlarındaki yalancı hurma ağaçlarında (*Phoenix canariensis*) oldukça zararlı olmuş (Atakan & Yüksel, 2008) ve Hurma ağaçlarında hızlı yayılış göstererek çok sayıda bitki kaybına neden olmuştur (Atakan & Gözel, 2013). Yapılan araştırmalar *P. canariensis*'in bu zararlıya oldukça duyarlı olduğunu, ancak *P. theophrasti*'nin duyarlılığına dair net bilgiler olmadığını bildirmektedir (Jacas ve diğerleri, 2011). Datça İlçesi, Bozburun bölgesinde yer alan *P. theophrasti* bireylerinde herhangi bir böcek zararına rastlanmadığı bildirilmiştir (Küçükala ve diğerleri, 2008). Ancak son yıllarda Muğla'nın Datça ilçesindeki palmiye türlerinde ölümler gözlenmiş ve bu durumun palmiye kırmızı böceğiyle ilişkili olabileceği belirtilmiştir (DKM, 2025). Doğa Koruma Merkezi tarafından yürütülen izleme çalışmaları, Datça hurması topluluklarının genel sağlık durumunun iyi olduğunu ortaya koymuştur (DKM, 2025). Bununla birlikte, zararlının *P. theophrasti* üzerindeki etkilerine ilişkin kesin verilere henüz ulaşılamamaktadır. Türün dünyada yalnızca Türkiye ve Girit'te doğal olarak yayılış göstermesi, onun korunması ve peyzaj uygulamalarında alternatif bir tür olarak değerlendirilmesi açısından çalışmayı önemli kılmaktadır.

Doğal bir türün ıslah süreci türün genel özelliklerinin belirlenmesi ile başlar. Ekolojik faktörlere ve kültürel uygulamalara tepkilerinin belirlenmesi ile devam eder. Türün çoğaltma olanakları, yetiştirme ortamlarındaki büyüme özellikleri ve gübre ihtiyacının belirlenmesi gibi araştırmalar da önem taşımaktadır (Henting, 1998; Durak & Karagüzel, 2022). *P. theoprasti* türünün, Türkiye'deki popülasyonlarının genetik karakterizasyonu (Vardareli & Göçmen Taşkın, 2012), Datça yarımadasındaki dağılımı (Boydak, 1985), meyvelerinin kimyasal birleşimi ve besin değeri (Liolios ve diğerleri, 2009) ile ilgili araştırmalar mevcuttur. Bunların yanı sıra tohumlarının çimlenmesi ile ilgili çalışmalarda dikkat çekmektedir (Çon, 2017; Parlak, 2023). Farklı yetiştirme ortamlarının *P. theoprasti* türünün fidelerinin büyüme özelliklerine etkisi ile ilgili çalışmalar incelendiğinde bunların son derece sınırlı olduğu tespit edilmiştir. Uzun & Söğüt (1998) genel olarak palmiyelerin birçok toprak yapısına uyum sağlayabildiklerini belirtirken, hızlı büyüyen türlerde çam kabuğu+ turba + kum (1:2:1); yavaş

büyüyen türlerde ise ağaç kabuğu+ turba+ kum (2:2:2) yetiştirme ortamının uygun olacağını belirtmiştirler. Esener (1999) ise palmiyelerin çok farklı toprak tipinde yetişebileceğini belirterek toprağa humus, çam kabuğu, torf ya da hindistan cevizi kabuğu eklenmesinin başlangıçta fide gelişimini hızlandırdığını bildirmiştir. Yüksek kalitede sağlıklı fide üretmek süs bitkileri yetiştiriciliği sektöründe büyük öneme sahiptir ve bu nedenle yetiştirme ortamının seçimi dikkat edilmesi gereken en önemli hususlardan biridir (Durak & Karagüzel, 2022). Yetiştirme ortamı seçimi ekonomik, kimyasal ve fiziksel özellikler dikkate alınarak yapılmalıdır (Barrett ve diğerleri, 2016; Rasool ve diğerleri, 2020).

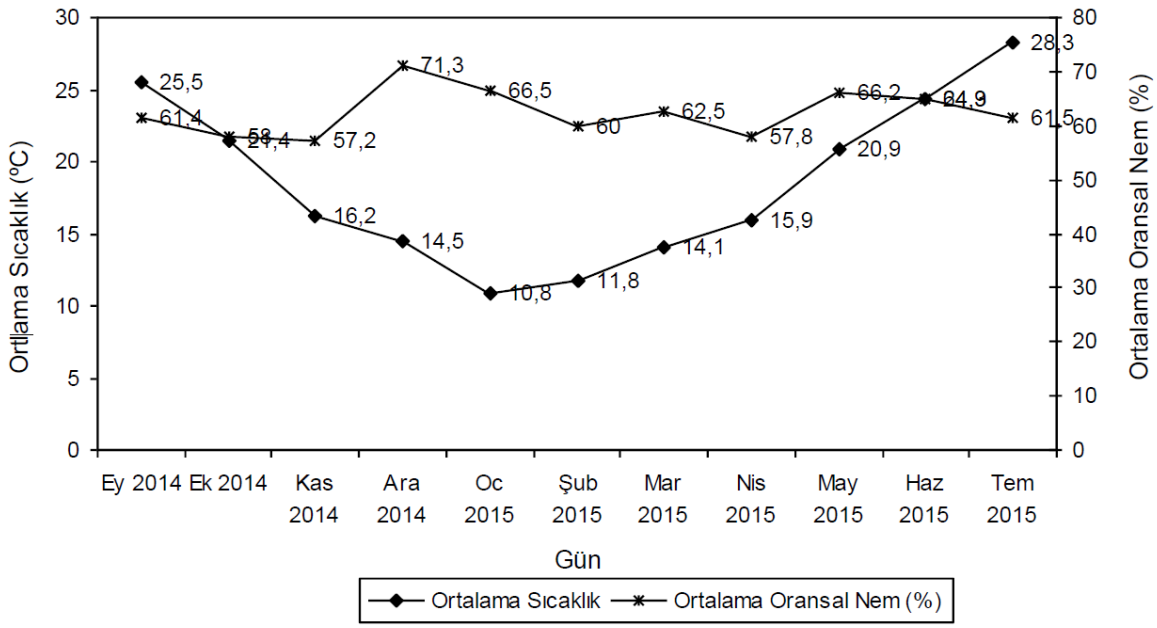
P. theophrasti birçok açıdan değerlendirilmiş olsa da büyüme koşulları ve farklı yetiştirme ortamlarının tür üzerindeki etkisi konusunda sınırlı sayıda çalışma mevcuttur. Bu çalışma *P. theophrasti* ve *P. theophrasti* subsp. *golkoy*'un farklı yetiştirme ortamlarındaki fidan büyüme özelliklerini belirlemeyi amaçlamaktadır.

2. Materyal ve Yöntem

Bitki materyali olarak Antalya İli, Kumluca İlçesi, Karaöz sınırları içerisinde doğal olarak yetişmekte olan *P. theophrasti* türü ile Muğla İli, Bodrum İlçesi, Göltürkbükü Beldesi sınırları içerisinde doğal olarak yayılış gösteren *P. theophrasti* subsp. *golkoy* alt türüne ait tohumlar ve tohumlardan elde edilen fidanlar kullanılmıştır.

Deneme Akdeniz Üniversitesi yerleşkesi içerisindeki arazide açık alan koşullarında gerçekleştirilmiştir. Çalışma üç tekerrürlü tesadüf parselleri deneme desenine göre 2014 yılı Mart ayı ile 2015 yılı Temmuz ayları arasında yürütülmüştür. Araştırma süresince kaydedilen veriler Antalya Meteoroloji Müdürlüğünden temin edilmiştir (Şekil 1).

2014-2015 yılları arasında denemenin yürütüldüğü dönemlerde gerçekleşen aylık minimum, ortalama ve maksimum sıcaklık değerleri Şekil 1'de verilmiştir. Aylık en yüksek sıcaklık değeri 2015 Temmuz ayında 40,9°C, en düşük sıcaklık değeri ise 2015 Ocak ayında -0.4°C olarak saptanmıştır. Ortalama sıcaklık değerleri bakımından en yüksek ortalama değerin, 2015 Temmuz ayında 28,3°C olduğu Şekil 1'de görülmektedir. Araştırma süresince aylara göre en yüksek ortalama nispi nemin 2014 yılı Aralık ayında %71,3 olduğu görülmektedir (Şekil 1).



Şekil 1. Araştırmanın yürütüldüğü dönemlerde gerçekleşen sıcaklık ve nispi nem değerleri (Yazarlar tarafından geliştirilmiştir)

Araştırmada farklı yetiştirme ortamlarının *P. theophrasti* taksonlarına ait tohumlardan elde edilen fidanların büyüme özelliklerine etkisinin belirlenmesi amaçlanmıştır.

Tınlı toprak+Yanmış çiftlik gübresi+Kum (2:1:1 hacimsel), Torf+Perlit (2:1 hacimsel), Torf+Kum (2:1 hacimsel) karışımlarını içeren üç farklı yetiştirme ortamı kullanılmıştır. Hazırlanan karışımlar 3 litre hacmindeki plastik saksılara doldurulmuştur. Tohumlar her bir saksıya 5 adet olmak üzere 3 cm derinliğe ekilmiştir. Tohumlar çimlendikten sonra en iyi durumda olan fide dışındakiler saksıdan alınmıştır. Deneme süresince 15 günde bir 15 mL gübre çözeltisi (100 ppm azot, 50 ppm fosfor ve 150 ppm potasyum) uygulaması gerçekleştirilmiştir.

Deneme tesadüf parselleri deneme deseninde kurulmuş olup, her yinelemede bir fidan bulunan 20 saksı değerlendirmeye alınmıştır. Deneme sonunda yaprak eni (cm), yaprak boyu (cm) ölçülmüş, yaprak sayısı (adet/bitki) tespit edilmiş ve yaprak örnekleri ile yetiştirme ortamı olarak kullanılan karışımlardan numune alınarak analiz yapılması sağlanmıştır.

Çalışmada elde edilen tüm veriler, SPSS 17 yazılımı kullanılarak varyans analizine tabi tutulmuş ve ortalamalar arasındaki farklar %5 önem düzeyinde Duncan çoklu karşılaştırma testiyle değerlendirilmiştir.

3. Bulgular ve Tartışma

Yetiştirme ortamlarının fiziksel ve kimyasal özellikleri içerdiği bileşenlerin özelliklerinden etkilenmektedir. Denemede kullanılan yetiştirme ortamlarının fiziksel ve kimyasal özellikleri. Tablo 1'de verilmiştir. Ortamların pH değerleri 5,53-7,8 arasında değişmiştir (Tablo 1). T+P karışımı diğer ortamlara göre daha yüksek bir elektriksel iletkenliğe (EC) (826,33 µS/cm) sahiptir. Yetiştirme ortamlarının kireç içeriği incelendiğinde aralarında istatistiksel fark olmazsın TT+YÇG+K ve T+K da bu değerin yüksek olduğu, T+P de ise diğer yetiştirme ortamlarına kıyasla bu değerin daha düşük olduğu görülmektedir (Tablo 1). Ayrıca T+P yetiştirme ortamında nem, su tutma kapasitesi ve organik madde miktarının önemli farkla diğer yetiştirme ortamlarından yüksek olduğu Tablo 1'de görülmektedir. Benzer şekilde azot, fosfor ve potasyum değerlerinin T+P yetiştirme ortamında daha yüksek olduğu saptanmıştır (Tablo 1). En yüksek kalsiyum ve magnezyum miktarları T+K yetiştirme ortamında saptanmış, en düşük değerler ise TT+YÇG+K yetiştirme ortamında saptanmıştır (Tablo 1).

Tablo 1. Yetiştirme ortamlarının deneme başında tespit edilen fiziksel ve kimyasal özellikleri

Özellik	Yetiştirme Ortamı			Önemlilik
	T+P	T+K	TT+YÇG+K	(*P* Değerleri)
pH	5,53 b	7,10 a	7,80 a[x]	*<0,001*
EC (µS/cm)	826,33 a	449,33 b	187,9 c	*<0,001*
Kireç (%)	3,44 b	26,27 a	25,33 a	*<0,001*
Nem (%)	12,00 a	5,00 b	9,33 ab	*<0,001*
Su Tutma Kapasitesi (%, Ağırlık)	832,67 a	148,67 b	82,67 c	*<0,001*
Organik Madde (%)	77,33 a	15,67 b	7,37 b	*<0,001*
Kül (%)	14,00 b	85,33 a	89,33 a	*<0,001*
N (%)	1,02 a	0,24 b	0,19 c	*<0,001*
P (mg L^{-1})	86,33 a	12,38 b	4,32 c	*<0,001*
K (mg L^{-1})	140,63 a	61,62 b	42,34 c	*<0,001*
Ca (mg L^{-1})	144,90 b	284,97 a	96,00 c	*<0,001*
Mg (mg L^{-1})	22,50 b	33,02 a	20,13 b	*<0,001*

T: Torf; P: Perlit; K: Kum; TT: Tınlı toprak; YÇG: Yanmış çiftlik gübresi

[x]: Satırlarda (her özellik içinde) Duncan testine göre % 5 önem düzeyinde farklı ortalamalar ayrı harflerle gösterilmiştir (Yazarlar tarafından geliştirilmiştir)

ANOVA sonuçları, takson, yetiştirme ortamı ve takson × yetiştirme ortamı interaksiyonunun *P. theophrasti*'nin bitki büyüme özellikleri üzerinde önemli etkileri olduğunu göstermiştir (Tablo 2). Denemede kullanılan yetiştirme ortamları *P. theophrasti* fidanlarının yaprak sayısı, yaprak boyu ve yaprak enini etkilemiştir (Tablo 2, Tablo 3). TT+YÇG+K ortamında yetiştirilen bitkilerde ortalama en yüksek bitki büyüme değerleri saptanırken, T+P ortamında ise bu değerlerin en düşük düzeyde olduğu görülmektedir (Tablo 3).

Tablo 2. *P. theophrasti* fidanlarının büyüme özelliklerine takson ve yetiştirme ortamının etkisine ilişkin varyans analizi (ANOVA) sonuçları

Varyasyon Kaynağı	df	Ortalama Kareler		
		Yaprak Sayısı (adet/bitki)	Yaprak Boyu (cm)	Yaprak Eni (cm)
Takson (T)	1	3,042***	79,380***	0,67*
Yetiştirme Ortamı (YO)	2	11,418***	15,520***	0,848**
T×YO	2	0,191ÖD	25,120***	0,174**
Hata	12	1,333	12,380	0,133

ÖD, *, **, ***: Önemli değil, sırasıyla *P*≤ 0,05, 0,01, 0,001 düzeyinde önemli (Yazarlar tarafından geliştirilmiştir)

Bu çalışma da kullanılan *P. theophrasti* taksonları bazı büyüme özellikleri bakımından önemli ölçüde çeşitlilik göstermiştir. Örneğin *P. theophrasti* (Karaöz/Kumluca) yaprak sayısı ve yaprak boyu açısından *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum)'den istatistiksel anlamda fark göstererek yüksek değerler almıştır (Tablo 3). Genetik farklılıkların yetiştirme ortamına verilen tepkiler üzerinde etkili olabileceğini göstermektedir. Bu durum fidanlık sahiplerine büyüme hızı bakımından alternatif sunması açısından önem taşımaktadır.

Tablo 3. *P. theophrasti* fidanlarının büyüme özelliklerine yetiştirme ortamı ve taksonların ana etkisi

Uygulamalar	Büyüme Özellikleri		
	Yaprak Sayısı (adet/bitki)	Yaprak Boyu (cm)	Yaprak Eni (cm)
Yetiştirme Ortamları			
T+P	4,7 b	26,8 b	1,4 b
T+K	4,9 b	27,4 ab	1,4 b
TT+YÇG+K	6,5 a[x]	29,0 a	1,9 a
Takson (Yöre)			
P. theophrasti (Karaöz/Kumluca)	5,8 a	29,8 a	1,5 a
P. theophrasti subsp. *golkoy* (Göltürkbükü/Bodrum)	4,9 b	25,6 b	1,6 a

T: Torf; P: Perlit; K: Kum; TT: Tınlı toprak; YÇG: Yanmış çiftlik gübresi

[x]: Her özellik altında ve her bir uygulama (sütun) içinde; Duncan testine göre % 5 önem düzeyinde farklı ortalamalar ayrı harflerle gösterilmiştir. (Yazarlar tarafından geliştirilmiştir)

Sonuçlar interaksiyon düzeyinde ele alındığında farklı yetiştirme ortamları ve taksonlar yaprak sayısı, yaprak boyu ve yaprak eni bakımından önemli farklar göstermiştir (Tablo 4).

Tablo 4. *P. theophrasti* fidanlarının büyüme özelliklerine yetiştirme ortamı ve taksonların interaksiyon etkisi

Özellik	Yetiştirme Ortamı	Takson (Yöre)	
		P. theophrasti (Karaöz/Kumluca)	*P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum)
Yaprak Sayısı	T+P	5,0 Ab	4,4 Ab
	T+K	5,3 Ab	4,4 Ab
	TT+YÇG+K	7,0 Aa[x]	6,0 Aa[y]
Yaprak Boyu	T+P	27,2 Ab	26,3 Aa
	T+K	30,4 Aa	24,3 Ba
	TT+YÇG+K	31,8 Aa	26,1 Ba
Yaprak Eni	T+P	1,4 Aa	1,4 Ab
	T+K	1,4 Aa	1,4 Ab
	TT+YÇG+K	1,7 Ba	2,1 Aa

T: Torf; P: Perlit; K: Kum; TT: Tınlı toprak; YÇG: Yanmış çiftlik gübresi

[x]: Büyük harfler yatay (satır boyunca) verilen ortalamaların, küçük harfler ise dikey (sütun boyunca) verilen ortalamaların karşılaştırmasını göstermektedir.

[y]: Duncan testine göre % 5 önem düzeyinde farklı ortalamalar ayrı harflerle gösterilmiştir. (Yazarlar tarafından geliştirilmiştir)

İnteraksiyon düzeyinde en yüksek yaprak sayısı TT+YÇG+K ortamında yetişen *P. theophrasti* (Karaöz/Kumluca) fidanlarında, en düşük yaprak sayısı ise T+K ve T+P ortamlarında yetişen *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) fidanlarında saptanmıştır (Tablo 4). Yaprak boyu

bakımından sonuçlar ele alındığında en yüksek değer TT+YÇG+K ortamında yetişen *P. theophrasti* (Karaöz/Kumluca) fidanlarında, en düşük değer ise T+K ortamında yetişen *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) fidanlarında belirlenmiştir. İkili interaksiyon düzeyinde yaprak en değerlerinin 1,4 ile 2,1 cm arasında değiştiği Tablo 4'de görülmektedir. En yüksek değer TT+YÇG+K ortamında yetişen *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) fidanlarında (2,1 cm) ölçülürken bu değeri aynı ortamda yetişen *P. theophrasti* (Karaöz/Kumluca) fidanlarının izlediği görülmektedir (Tablo 3).

P. theophrasti fidanlarının bazı yaprak besin elementi içeriklerine yetiştirme ortamlarının etkisi ile ilgili veriler Tablo 5'de görülmektedir.

Tablo 5. *P. theophrasti* fidanlarında yaprak besin elementi içeriklerine yetiştirme ortamlarının etkisi

Besin Elementi	Takson (Yöre)	Yetiştirme Ortamı			*Önemlilik*
		T+P	T+K	TT+YÇG+K	(P Değerleri)
N (%)	1	1,71 a	1,53 a	1,87 a[x]	*0,765*
	2	2,31 a	2,10 a	2,01 a	*0,189*
P (%)	1	0,12 a	0,12 a	0,13 a	*0,266*
	2	0,09 c	0,14 b	0,19 a	*0,002*
K (%)	1	0,64 a	0,87 a	0,86 a	*0,508*
	2	0,83 a	1,03 a	0,83 a	*0,774*
Ca (%)	1	0,39 a	0,40 a	0,32 a	*0,073*
	2	0,40 a	0,44 a	0,46 a	*0,596*
Mg (%)	1	0,16 a	0,15 a	0,13 a	*0,450*
	2	0,11 a	0,13 a	0,09 a	*0,678*
Fe (ppm)	1	74,43 b	95,07 b	209,60 a	*<0,001*
	2	106,63 b	112,70 b	249,97 a	*<0,001*
Mn (ppm)	1	14,63 b	25,10 a	14,00 b	*0,006*
	2	10,33 b	18,83 a	16,10 a	*0,016*
Zn (ppm)	1	1,53 a	1,30 a	1,50 a	*0,937*
	2	3,53 a	1,37 b	1,20 b	*0,003*
Cu (ppm)	1	9,50 a	7,87 a	9,10 a	*0,369*
	2	13,60 a	9,07 b	8,13 b	*0,019*

1: *P. theophrasti* (Karaöz/Kumluca), 2: *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum)
T: Torf; P: Perlit; K: Kum; TT: Tınlı toprak; YÇG: Yanmış çiftlik gübresi
[x]: Satırlarda (besin elementi) ve her takson içinde; Duncan testine göre % 5 önem düzeyinde farklı ortalamalar ayrı harflerle gösterilmiştir. (Yazarlar tarafından geliştirilmiştir)

Yetiştirme ortamlarına bağlı olarak yaprak fosfor, demir, mangan, çinko ve bakır içeriklerinde önemli düzeyde farklar tespit edilmiştir (Tablo 5). TT+YÇG+K ortamında yetişen *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) fidanlarının önemli farkla en yüksek yaprak fosfor içeriğine sahip olduğu saptanmıştır (Tablo 5). Yaprak demir ve mangan içerikleri her iki taksonda da yetiştirme ortamlarına bağlı olarak önemli fark göstermiştir. TT+YÇG+K yetiştirme ortamında yer alan fidanların en yüksek yaprak demir içeriğine sahip olduğu Tablo 5'de görülmektedir. Yaprak mangan içerinin ise T+K yetiştirme ortamında yer alan fidanlarda yüksek olduğu belirlenmiştir (Tablo 5). *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) fidanlarının yaprak çinko ve bakır içeriklerinin de yetiştirme ortamına bağlı olarak önemli farklar gösterdiği, en yüksek değerlerin ise T+P yetiştirme ortamında yer alan fidanların yapraklarında saptandığı Tablo 5 'de görülmektedir.

Korelasyon analizleri yaprak besin elementi içerikleri ile *P. theophrasti* taksonlarının büyüme özellikleri arasında birkaç önemli pozitif ve negatif korelasyon olduğunu ortaya koymuştur (Tablo 6). Yaprak demir içeriği ile yaprak sayısı arasında önemli pozitif korelasyon, yaprak kalsiyum içeriği ile yaprak boyu arasında ve yaprak magnezyum ve demir içeriği ile yaprak eni arasında önemli ve negatif korelasyon saptanmıştır (Tablo 6).

Tablo 6. *P. theophrasti* fidanlarının büyüme özellikleri ve yaprak besin elementi içerikleri arasındaki ilişkiler

	Büyüme Özellikleri			Yaprak Besin Elementleri							
	Yaprak Sayısı	Yaprak Boyu	Yaprak Eni	N	P	K	Ca	Mg	Fe	Mn	Zn
Yaprak Boyu	**0,713**										
	0,001										
Yaprak Eni	**0,593**	0,024									
	0,010	*0,924*									
N	-0,209	-0,401	-0,088								
	0,406	*0,100*	*0,730*								
P	0,372	-0,211	0,845	-0,096							
	0,128	*0,400*	*<0,001*	*0,705*							
K	-0,133	0,035	-0,137	-0,091	0,020						
	0,598	*0,891*	*0,588*	*0,721*	*0,939*						
Ca	-0,262	**-0,529**	0,147	-0,055	0,356	0,067					
	0,293	*0,024*	*0,560*	*0,829*	*0,147*	*0,791*					
Mg	-0,229	0,140	**-0,524**	-0,104	-0,296	0,449	-0,269				
	0,361	*0,580*	*0,025*	*0,682*	*0,234*	*0,062*	*0,280*				
Fe	**0,712**	0,144	**0,886**	0,130	**0,758**	0,005	0,037	-0,446			
	0,001	*0,569*	*<0,001*	*0,607*	*<0,001*	*0,983*	*0,884*	*0,063*			
Mn	0,026	0,137	-0,086	-0,202	0,104	-0,041	0,287	0,169	-0,144		
	0,919	*0,589*	*0,734*	*0,422*	*0,683*	*0,870*	*0,248*	*0,502*	*0,570*		
Zn	-0,374	-0,133	-0,285	0,308	-0,391	0,052	-0,178	0,080	-0,236	**-0,517**	
	0,126	*0,599*	*0,252*	*0,214*	*0,109*	*0,836*	*0,481*	*0,752*	*0,347*	*0,028*	
Cu	-0,425	-0,253	-0,376	0,329	-0,348	0,094	0,030	0,175	-0,240	**-0,519**	**0,900**
	0,079	*0,310*	*0,124*	*0,183*	*0,157*	*0,711*	*0,907*	*0,487*	*0,338*	*0,027*	*<0,001*

İstatistiksel anlamda önemli olan ilişkiler koyu, P değerleri ise italik yazılmıştır (Yazarlar tarafından geliştirilmiştir)

Her iki taksonda da incelenen büyüme özelliklerinin yetiştirme ortamına bağlı olarak değiştiği görülmektedir. Sonuçlar Uzun & Söğüt (1998) ile Esener (1999)'in verdiği bilgilerle genel olarak uyumludur. Uzun & Söğüt (1998) organik madde içeriği ve karışımın fiziksel özelliğinin gelişim üzerinde belirleyici olduğunu vurgulamış ve organik maddece zengin ve iyi drene olan ortamların en uygun seçenek olduğunu bildirmişlerdir. Esener (1999) ise farklı organik materyallerin fide gelişimini özellikle erken dönemde hızlandırdığını belirtmiştir. Bu çalışmalar, palmiye türlerinin performansında yetiştirme ortamının organik içeriğinin, gözenekliliğinin ve su tutma kapasitesinin bitki büyüme performansı açısından önemli rol oynadığını göstermektedir. Bu çerçevede, mevcut çalışmada TT+YÇG+K yetiştirme ortamında her iki taksonda da en yüksek büyüme değerlerinin saptanması, literatür ile uyumlu bir bulgudur. Yanmış çitlik gübresinin ortama sunduğu yüksek organik madde ve besin elementleri, tınlı toprağın su tutma kapasitesi ve kumun drenajı desteklemesi Uzun & Söğüt (1998)'ün 'organik maddece zengin fiziksel açıdan dengeli ortam' önerileriyle örtüşmektedir.

Fidanlıklarda bitki yetiştirmek için kullanılan yetiştirme ortamları genellikle torf ve perlit içerir. Ancak bu ortamlar mevcut kullanılabilir organik madde azlığından dolayı yoğun kimyasal gübre kullanımı gerektirir (Durak & Karagüzel, 2022). Bu nedenle, sınırlı gübre kullanımı T+K ve T+P yetiştirme ortamlarında bitki büyüme özellikleri bakımından daha düşük değerler saptanmıştır. TT+YÇG+K yetiştirme ortamında ise besin elementleri içeriğinin daha yüksek olduğu tespit edilmiştir. TT+YÇG+K ortamında en yüksek büyüme değerlerinin saptanması, yanmış çiftlik gübresinin sunduğu organik madde ve besin elementleri ile tınlı toprağın su tutma kapasitesi ve kumun drenajı destekleyici etkilerinin bir araya gelmesinden kaynaklanmaktadır. Torf içeren karışımların organik madde içermesine rağmen alınabilir besin elementleri bakımından zayıf olması ve deneme süresince gerçekleştirilen sınırlı gübreleme T+K ve T+P ortamlarında *P. theophrasti* fidanlarının gelişiminde dezavantaj yaratmıştır.

Yetiştirme ortamlarının Phoenix türlerine etkileriyle ilgili sınırlı sayıda çalışma olması nedeniyle bu çalışmanın sonuçlarını önceki çalışmalar ışığında fide büyüme özellikleri açısından değerlendirmek zordur. Fidanlıklar genellikle yetiştirme ortamı olarak torf kullanmayı tercih etse de çevresel kaygılar birçok ülkede torf çıkarma sürecini sınırlamakta ve buda fiyatının yükselmesine neden olmaktadır (Zulfiqar ve diğerleri, 2019; Stewart-Wade, 2020) . Bu durum diğer organik malzemelerin torf yerine alternatif olarak kullanılma potansiyelleri açısından araştırılmasına neden olmuştur (Zulfiqar ve diğerleri, 2019). Bu nedenle en iyi gelişimin TT+YÇG+K ortamında saptanması önem taşımaktadır.

Durak & Karagüzel (2022) *Celtis australis* türünün farklı yetiştirme ortamlarında büyüme özelliklerini incelemişlerdir. Araştırmalarında, kum, tınlı toprak, torf, yanmış çiftlik gübresi, perlit ve atık mantar kompostunu farklı formülasyon ve oranlarda karıştırarak 4 farklı yetiştirme ortamı kullanmışlardır. Fidan büyüme özellikleri bakımından en iyi sonuç Atık mantar kompostu + Kum ile Yanmış çiftlik gübresi+Tınlı toprak +Kum ortamlarında görülmüştür. Çalışmamızla farklı tür olsa da her iki türün doğal yayılış alanları bakımından benzer ekolojik koşullara sahip olduğu göz önüne alındığında ortak bir zemin oluşmaktadır. Her iki çalışmada da organik maddece zengin ve iyi drene olan yetiştirme ortamlarının fide gelişimini desteklediği yönünde benzer sonuçlar elde edilmiştir.

4. Sonuç ve Öneriler

Çalışma kapsamında, tohumdan elde edilen *P. theophrasti* ve *P.theophrasti* subsp. *golkoy* fidanlarının farklı yetiştirme ortamlarındaki büyüme özellikleri ile ilgili veriler değerlendirilmiştir. Sonuçlar her iki taksonda da incelenen büyüme özelliklerinin yetiştirme ortamına bağlı olarak değiştiğini göstermektedir.

Doğal türlerin peyzaj alanlarında kullanılmasıyla ortaya çıkan ekonomik ve ekolojik yararlar bu türlerin giderek fazla tercih edilmesini sağlamakta bu nedenle peyzaj alanlarına doğal türleri kazandırmak büyük önem taşımaktadır. Araştırmada sınırlı bir gübreleme programı uygulanmasına rağmen, çalışmanın sonuçları sürdürülebilir bir gübreleme programı ile çevre dostu *P. theophrasti* yetiştiriciliğinin gerçekleştirilebileceğini göstermektedir.

Sonuçlar *P. theophrasti* (Karaöz/ Kumluca) fidanlarının Yanmış çiftlik gübresi + Tınlı toprak + Kum (1:2:1 hacimsel) ortamında en iyi büyüme özelliklerine sahip olduğunu göstermektedir. Bu ortam kolay temin edilebilirlik açısından da avantaj sağlamaktadır.

Teşekkür ve Bilgi Notu

Bu makale, Akdeniz Üniversitesi Fen Bilimleri Enstitüsü Peyzaj Mimarlığı Ana Bilim Dalı'nda 2017 yılında tamamlanan "Datça Hurması (*Phoenix theophrasti-Phoenix theophrasti* subsp. *golkoy*)'nın Çimlenme ve Fidanlarının Farklı Yetiştirme Ortamlarında Büyüme Özelliklerinin Belirlenmesi" adlı Yüksek Lisans tezinin bir kısmından üretilmiştir. Makale ulusal ve uluslararası araştırma ve yayın etiğine uygundur. Çalışma için Etik Kurul onayı gerekmemektedir.

Yazar Katkısı ve Çıkar Çatışması Açıklama Bilgileri

1. Yazar %60, 2. yazar %40 katkıda bulunmuştur. Çıkar çatışması yoktur.

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Effects of Different Growing Media on the Growth Characteristics of Datça Palm (*Phoenix theophrasti-Phoenix theophrasti* subsp. *golkoy*) Seedlings

Summary

The growing interest in natural landscape design has significantly increased the use of native plant species due to their ecologically sustainable and nature-restorive characteristics (Durak & Karagüzel, 2022). The invasive potential of foreign species and their negative effects on ecosystems contribute to the increased preference for native species in landscape design. Turkey has significant potential for the ornamental plant sector due to its rich plant genetic resources, and rapid changes in the sector are increasing the need for new species and cultivars. Therefore, both the correct species selection and the use of up-to-date techniques in production are necessary (Selim & Durak, 2025).

Palms are characteristic plants of tropical and subtropical regions and include numerous genera and species (Pamay, 1992). *Phoenix theophrasti*, which occurs naturally in Turkey, is found on the coasts of Muğla and Antalya; its subspecies, *P. theophrasti* subsp*. golkoy*, is found only in Muğla (Boydak & Barrow, 1995; Esener, 1999). Apart from these two taxa, all palms cultivated in the country are exotic species (Hazır & Büyüköztürk, 2013). *P. theophrasti*, which has high landscape value, thrives in Mediterranean climates and moist, well-drained soils (Pamay, 1992).

The importation of foreign palm species has led to the introduction of the red palm weevil (*Rhynchophorus ferrugineus*) into the country, causing significant losses in many species (Hazır & Büyüköztürk, 2013; Karut & Kazak, 2005; Atakan & Gözel, 2013). While *P. canariensis* is known to be highly susceptible to the pest, the susceptibility of *P. theophrasti* has not been fully established (Jacas et al., 2011). No pests were detected in *P. theophrasti* individuals during observations conducted in the Datça-Bozburun Peninsula (Küçükala et al., 2008). However, in recent years, some palm deaths in Datça have been associated with the red palm weevil (DKM, 2025). Although the Nature Conservation Center's monitoring studies report that the general condition of the populations is good, information on the actual effects of the pest on *P. theophrasti* has not yet been obtained (DKM, 2025). The fact that the species is naturally distributed only in Turkey and Crete worldwide makes this study important in terms of its conservation and evaluation as an alternative species in landscape practices.

The breeding process in natural species begins with determining the species' characteristics, ecological requirements, responses to the growing media, and propagation possibilities (Henting, 1998; Durak & Karagüzel, 2022). Research on *P. theophrasti* has focused on areas such as genetic structure (Vardareli and Göçmen Taşkın, 2012), distribution (Boydak, 1985), fruit chemistry (Liolios et al., 2009), and seed germination (Çon & Karagüzel, 2017; Parlak, 2023). However, studies on the effect of different growing media on seedling growth are limited. It has been reported that palms can adapt to many soil types and that organic matter additions positively affect seedling development (Uzun & Söğüt, 1998; Esener, 1999). The choice of growing medium is important in terms of both economic and physical-chemical properties (Barrett et al., 2016; Rasool et al., 2020).

Within this framework, the study aims to examine the seedling growth characteristics of *P. theophrasti* and its subspecies *P. theophrasti* subsp. *golkoy* in different growing media.

In the study, seeds from the *P. theophrasti* species naturally growing in the Karaöz region of Kumluca District, Antalya Province, and seeds from the *P. theophrasti* subsp. *golkoy* subspecies naturally occurring in Göltürkbükü, Bodrum District, Muğla Province, as well as seedlings obtained from these seeds, were used as plant material. The experiment was conducted at the Akdeniz University campus under open field conditions, using a randomized block design with three replications; the study covered the period from March 2014 to July 2015.

Climate data for the trial period was obtained from the Antalya Meteorological Directorate. During this period, the minimum temperature was recorded at -0.4°C in January 2015, while the maximum

temperature was recorded at 40.9°C in July 2015. The average temperature reached its highest value in July 2015 at 28.3°C, while the highest average relative humidity was 71.3% in December 2014.

The aim of the study is to determine the growth characteristics of seedlings obtained from seeds belonging to two *P. theophrasti* taxa under different growing media. For this purpose, three different growing media were prepared: Well fermented manure + Loamy soil + Sand (1:2:1, volumetric); Peat+ Perlite (2:1, volumetric) and Peat + Sand (2:1, volumetric). The prepared mixtures were filled into 3L plastic pots; five seeds were sown in each pot at a depth of 3 cm. After germination, the healthiest seedling was left, and the others were removed. During the trial period, 15 mL of fertilizer solution (100 ppm N, 50 ppm P, and 150 ppm K) was applied every 15 days.

The experiment was conducted according to the randomized block design, and a total of 20 pots, each containing one seedling, were evaluated in each replication. At the end of the experiment, leaf number (number/plant), leaf length (cm), and leaf width (cm) were measured; leaf and growing medium samples were also collected for analysis. All data obtained were subjected to variance analysis using SPSS 17 software; differences between means were determined using Duncan's multiple comparison test at a 5% significance level.

The physical and chemical properties of growth media are influenced by the properties of the components they contain. The pH values of the growth media used in the experiment ranged from 5.53 to 7.8. The T+P mixture had a higher electrical conductivity (EC) (826.33 µS/cm) compared to the other media. When the lime content of the growing media was examined, no statistical difference was found between them. TT+YÇG+K and T+K were found to have high values, while T+P had lower values compared to other growing media. In addition, moisture, water holding capacity, and organic matter content in the T+P growing medium were significantly higher than in other growing media. Similarly, nitrogen, phosphorus, and potassium values were found to be higher in the T+P growing medium. The highest calcium and magnesium amounts were found in the T+K growing medium, while the lowest values were found in the TT+YÇG+K growing medium.

ANOVA results showed that taxon, growing medium, and taxon × growing medium interaction had significant effects on the plant growth characteristics of *P. theophrasti*. The growing media used in the experiment affected the number of leaves, leaf length, and leaf width of *P. theophrasti* seedlings. The highest average plant growth values were observed in plants grown in the TT+YÇG+K medium, while the lowest values were observed in the T+P medium.

The *P. theophrasti* taxa used in this study showed significant variation in terms of certain growth characteristics. For example, *P. theophrasti* (Karaöz/Kumluca) showed statistically significant differences in leaf number and leaf length compared to *P. theophrasti* subsp. golkoy (Göltürkbükü/Bodrum), exhibiting higher values. This is important in terms of offering nursery owners an alternative in terms of growth rate.

When results are considered at the interaction level, different growing environments and taxa showed significant differences in terms of leaf number, leaf length, and leaf width.

The highest number of leaves at the interaction level was observed in *P. theophrasti* (Karaöz/Kumluca) seedlings grown in the TT+YÇG+K growing medium, while the lowest number of leaves was observed in *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) seedlings grown in the T+K and T+P medium. In terms of leaf length, the highest values were found in *P. theophrasti* (Karaöz/Kumluca) seedlings grown in the TT+YÇG+K medium, while the lowest values were found in *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) seedlings grown in the T+K environment. At the level of binary interaction, leaf width values were found to vary between 1.4 and 2.1 cm. The highest value was measured in *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) seedlings grown in the TT+YÇG+K medium (2.1 cm), followed by *P. theophrasti* (Karaöz/Kumluca) seedlings grown in the same medium.

Data on the effect of growing media on certain leaf nutrient element contents of *P. theophrasti* seedlings were examined. Leaf phosphorus, iron, manganese, zinc, and copper contents showed significant differences depending on the growing medium. It was determined that *P. theophrasti*

subsp. *golkoy* (Göltürkbükü/Bodrum) seedlings grown in the TT+YÇG+K medium had the highest leaf phosphorus content with a significant difference. Leaf iron and manganese contents showed significant differences in both taxa depending on the growing medium. Seedlings in the TT+YÇG+K growing medium were found to have the highest leaf iron content. Leaf manganese content was found to be high in seedlings grown in the T+K growing medium. Leaf zinc and copper contents of *P. theophrasti* subsp. *golkoy* (Göltürkbükü/Bodrum) seedlings also showed significant differences depending on the growing medium, with the highest values found in the leaves of seedlings grown in the T+P growing medium.

Correlation analyses revealed several significant positive and negative correlations between leaf nutrient element contents and growth characteristics of *P. theophrasti* taxa. A significant positive correlation was found between leaf iron content and leaf number, while significant negative correlations were observed between leaf calcium content and leaf length, and between leaf magnesium and iron content and leaf width.

This study shares the results regarding the growth characteristics of *P. theophrasti* and *P. theophrasti* subsp. *golkoy* seedlings obtained from seeds in different growing media. The results show that the growth characteristics examined in both taxa vary depending on the growing environment. The results are generally consistent with the information provided by Uzun and Söğüt (1998) and Esener (1999). Uzun and Söğüt (1998) emphasized that organic matter content and the physical properties of the mixture are decisive for development and reported that organic matter-rich and well-drained environments are the most suitable options. Esener (1999) stated that different organic materials accelerate seedling development, especially in the early stages. These studies show that the organic content, porosity, and water retention capacity of the growing medium play an important role in the growth performance of palm species. In this context, the finding that the highest growth values were observed in both taxa in the TT+YÇG+K growing medium in the current study is consistent with the literature. The high organic matter and nutrient elements provided by well fermented manure, the water retention capacity of loamy soil, and the drainage support of sand are consistent with Uzun and Söğüt's (1998) recommendations for an ‘organic matter-rich, physically balanced medium’.

The growing media used for cultivating plants in nurseries typically contain peat and perlite. However, due to the scarcity of available organic matter, these media require intensive chemical fertilizer use (Durak & Karagüzel, 2022). Therefore, limited fertilizer use in T+K and T+P growing media resulted in lower plant growth values compared to the nutrient-rich TT+YÇG+K growing medium. Although mixtures containing peat contain organic matter, they are poor in terms of available nutrients, and the limited fertilization carried out during the trial period created a disadvantage in the development of *P. theophrasti* seedlings in T+K and T+P environments.

Due to the limited number of studies on the effects of growing media on Phoenix species, it is difficult to evaluate the results of this study in terms of seedling growth characteristics in light of previous studies. Although nurseries generally prefer to use peat as a growing medium, environmental concerns are limiting peat extraction in many countries, leading to price increases (Zulfiqar et al., 2019; Stewart-Wade, 2020). This situation has led to research into the potential of other organic materials as alternatives to peat (Zulfiqar et al., 2019). Therefore, it is important to determine the best growth in the TT+YÇG+K medium.

Durak & Karagüzel (2022) examined the growth characteristics of *Celtis australis* in different growing media. In their research, they used four different growing media by mixing loamy soil, sand, well fermented manure, peat, perlite, and waste mushroom compost in different formulations and ratios. The best results in terms of seedling growth characteristics were observed in the waste mushroom compost + sand and loamy soil + well fermented manure + sand media. Although our study involved a different species, considering that both species have similar ecological conditions in terms of their natural distribution areas, there is common ground. Both studies obtained similar results indicating that growing media rich in organic matter and well-drained support seedling development.

The economic and ecological benefits arising from the use of native species in landscape areas are leading to their increasing preference; therefore, introducing native species into landscape areas is of

great importance. Despite the limited fertilization program applied in the study, the results indicate that environmentally friendly *P. theophrasti* cultivation can be achieved with a sustainable fertilization program. The results show that *P. theophrasti* (Karaöz/Kumluca) seedlings exhibit the best growth characteristics in an environment consisting of well fermented manure + loamy soil + sand (1:2:1 by volume). This environment also offers the advantage of being readily available.

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