European Journal of Applied Sciences – Vol. 13, No. 01
Publication Date: February 25, 2025
DOI:10.14738/aivp.1301.18176.
Sahin, C. K., & Merdan, R. (2025). Surface Behaviors of Pine Wood (*Pinus nigra*) After Short-Term Weathering: Urban Furniture Suitability Investigation. European Journal of Applied Sciences, Vol - 13(01). 98-109.

Surface Behaviors of Pine Wood *(Pinus nigra)* After Short-Term Weathering: Urban Furniture Suitability Investigation

Candan Kus Sahin
Suleyman Demirel University, Architecture Faculty,
Department of Landscape Architecture Isparta, Turkiye

Rahim Merdan
Isparta University of Aplied Sciences, Keçiborlu Vocational School,
Department of Interior Design, Isparta, Turkiye

ABSTRACT

The tangential/radial ratio (T/R) has usually been used to investigate wood's physical properties due to moisture uptake and loss differences. In this issue, the color coordinate differences were evaluated between two surfaces for Black pine (*Pinus nigra*). Initially (controls), it was measured to be a (T-R) L*: 10.71 1.45 (metric) difference for lightness, (T-R) a*: -0.07 (metric) for a* coordinate, and (T-R) b*:- 0.14 (metric) for the b* coordinates. However, the total color changes (discoloration) of two surfaces were found to be after outdoor exposure, separately. The tangent surface shows ΔE_T: 10.71 (metric), which is higher than the radial surface values of ΔE_R: 8.57 (metric) after weathering. The chroma and hue differences were observed to be negligible for control and weathered samples, with only <2.0 units differences for both surfaces. A similar trend was also observed for gloss properties: all gloss differences were found to be <3.0 Gu which could not be visually differentiated easily. The radial surface seemed to have a higher yellowness value than tangent surfaces, which was found to be YI_R: 52.70 (numeric) for radial surfaces and YI_T: 47.62 (numeric) for tangent surfaces. After weathering, considerably lower X-(red), Y-(yellow) and Z-(blue) stimuli values were calculated: ΔXT(w-c):-12.68 (numeric) in tangent and ΔXR(w-c): -10.67 (numeric) in radial surface for X stimuli, ΔYT(w-c): -12.47 (numeric) in tangent- and ΔXR(w-c): -10.46 (numeric) in radial surface for Y stimuli; and ΔZT(w-c): -7.28 (numeric) for tangent and ΔZR(w-c): -7.42 (numeric) in radial surface for Z stimuli, respectively.

Keywords: Black pine, urban furniture, tangent and radial surface, weathering, discoloration.

INTRODUCTION

Furniture could be categorized as places where it is used for either indoor- or outdoor applications [1]. However, urban and street furniture are generally seen as the same terms, and both are used for similar meanings. In general, the urban furniture stands for open space, and it is used by the public [2, 3]. The urban space offered many ways of using the ambient equipment in compliance with a high standard of life quality for the city inhabitants [2, 4]. However, numerous types of urban furniture can be made from a variety of materials, providing a leisurely, pleasant, dynamic or relaxing atmosphere with comfort. Some of the common examples of those objects are sidewalks, parking elements, benches, bus stops, streetlights, sign boards, bike racks, plant boxes, tables, signage, litter bins, shelters, streets, playground equipment's, and so on [5 6]. Due to those diversities, there are many ways to categorize urban furniture [1].

The diversity of materials could be useful for urban furniture objects that create an enjoyable atmosphere, can serve a function, be aesthetic or both [3, 4]. As a result of technological developments, the many of natural or artificial elements, such as ceramics, glass, metal, concrete, plastic, wood, and synthetic polymers, could be useful for urban furniture manufacturing [7, 8]. However, appearance is a very important characteristic, influencing some physical or psycho-emotional effects [3, 4, 8]. It is important to note that the urban spaces are accessible to all types of users, including children, youth, disabled or elderly users [4]. Therefore, open space designers must take into account the diverse user groups interacting with those established urban furniture elements. Because the presence of inadequate objects, such as uncomfortable seating, a dissatisfying view, or an unwanted odor from nearby, could have a negative experience for users [9]. On the other hand, those negative impacts could be overcome by selecting a good place to establish with proper elements made from suitable materials. Regarding those issues, wood is usually suggested to be one of the best choices for urban furniture manufacturing [3, 10]. Besides its sustainability and pleasant natural colors, it is also an easier-to-work with and more cost-effective material than many other materials (e.g., concrete, steel, ceramic). There are numerous reports on the advantages of using wooden objects in architectural design practices, which could be found further information elsewhere [3, 10-12].

Typically, wood has a pleasing visual appearance that is expected to fulfill the aesthetic requirements for open-space designs. Therefore, general wood surface textures such as color, grain and lust are some of the important properties for the attractive appearances in urban furniture applications [11]. However, the wood property classification relies on qualified design professionals that analyze texture patterns and characteristics on timbers, which could be a difficult task. In this case, a good knowledge of this topic of determining and using certain species and plane directions of wood is helpful for sustainability and effective utilization of wood.

The wood surfaces are not uniform, since they are composed of different types of cells and regions (e.g., late wood-early wood, sapwood-heartwood). Those variations cause color differences even among the same wood species [13]. Regarding this heterogeneity, when wood is exposed to outdoor environments, the natural color changes at different rates for different surfaces of the same wood pieces under similar conditions [11, 14]. In wood, knowledge of stiffness, strength, toughness and aesthetic properties is of primary importance to customers, manufacturers and designers. However, the relationship between the strength and aesthetic properties of wood has received a great deal of attention in the architectural context. On the other hand, the different surface behaviors of wood have been somewhat neglected, particularly in the context of urban furniture applications [7, 10, 15]. While some limited research has been done in the areas of strength and toughness properties, for the surface deformations of wood along or across the grains in anatomical things, very little systematic work has been conducted in terms of physicochemical properties [3, 7, 10]. But the tensile stresses at different directions of planes may lead to more cracking or splitting in one direction than another, which could lead to the failure of wooden objects as urban furniture functions.

The aim of this study is to evaluate the variability of Black pine wood (*Pinus nigra*) color before and after outdoor exposure. The tangent and radial surfaces of the same wood species were investigated, comparatively, regarding their appeal as urban furniture material.

MATERIAL AND METHODS

A specially prepared, a softwood species of Black pine *(Pinus nigra)* was selected for the experiments. The boards were supplied from a local market, Isparta-Turkiye and small samples were cut into 50 mm x 50 mm x 10 mm pieces and conditioned at 20°C and 65 % relative humidity to reach an air-dry moisture content of 12%. The natural outdoor exposure (weathering process) was conducted on the south side of a park (Cunur Park) located in Isparta-Turkiye. The specially prepared tangent and radial apparent samples were aged outdoors for six months, during which the optical measurements were taken before outdoor exposure (as a control) and after for radial and tangent surfaces, respectively. The total of 20 specimens were used for conducting this research.

The discoloration of wood specimens was determined using a color spectrophotometer (X-Rite SP 968 Spectrophotometer). Measurements were made using standard illumination and a standard observer. The CIE L*a*b* (CIE, 1976), where L* stands for lightness, a* stands for redness-greeness, and b* stands for yellowness-blueness, was used to quantify the changes in color. The total color changes (ΔE*) were determined with using the following equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad [1]$$

Where: ΔL*, Δa* and Δb* are the changes in the color coordinates L*, a* and b* for the respective time intervals.

Δh stated color hue difference values, with respect to color coordinate values (L*a*b*) and chromacity (C*).

$$\Delta h^*ab = [(\Delta E^*ab)^2 - (\Delta L^*)^2 - (\Delta C^*ab)^2]½ \quad [2]$$

A positive sign indicates a counterclockwise change of hue, a negative sign indicates a clockwise change in color space.

The CIE XYZ (1931) tristimulus method was also used to evaluate color changes, where X stimuli stand for red, Y stimuli stand for yellow, and Z stimuli stand for blue. Yellowness is associated with a general product degradation by light, chemical exposure, and processing. Yellowness indices are used mainly to measure these types of degradation. In this regard, the yellowness index (YI) was found according to the ASTM Method E313 standard, which is calculated as follows:

$$YI: (100(CxX - CzZ))/Y \quad [3]$$

Where X, Y, and Z are the CIE Tristimulus values, and the coefficients depend on the illuminant and observer.

The gloss measurements were carried out with a 600 Gloss meter (Pacific Scientific Glossgard II, 60º gloss meter, MI) followed in international standard ISO 2813. Due to many combinations were utilized during the experiments, for simplicity, some code numbers and abreviations were established throughout the study, as given in Text, Figures and Tables. These are: C: control (unweathered), w: outdoor exposure (weathered), 0: initial color of sample, T: tangent surface wood and R: Radial surface wood.

RESULTS AND DISCUSSIONS

The size, shape, and arrangement of cells vary considerably between two surfaces of the same wood, even the constituents are relatively constant within a species [7, 16]. This is due to the cut of the plane of wood. In general, a longitudinal cut (plain or flat sawn) in a plane at a tangent to annual rings is called the tangential surface (T0), while a cut plane that runs longitudinally from the center of the trunk to the bark is called the radial section (R0) [16]. Figure 1 shows two different cut surfaces of the same wood species (Pine wood) were once prepared and established as urban furniture (sidewalks) in a park for years. In terms of the homogeneity, tangentially prepared wood surfaces appeared to initiate some cracks (D and E) and splits (F) during the outdoor exposure compared to radial surfaces (A and B). This could be attributed to the different light-induced weathering reactions, as well as the rate at which wetting-drying proceeds under outdoor exposure conditions. In many wood research reports, the tangential/radial ratio (T/R) has been extensively used to evaluate wood properties in certain species [16-18]. Consistently, they have reported that the tangential surface loses moisture or shrinkage about two times faster than the radial surface. It has also been proposed that it is much easier to split wood along the grain than to break it across it [16-18]. Those directly impact the properties of the same wood species under similar conditions. These are clearly visible in Figure 1F. Thuvander and Berglund (2000) conducted research on Scotch pine wood to describe the micromechanisms of crack growth by in-situ optical microscopy [19]. They found that the stress distribution in a material like wood with alternating stiff and soft layers (e.g., growth rings) could be causing stress, which contributes to the tendency for inclined cracks to deviate in the radial direction [16, 18]. It has also been hypothesized that the splitting of wood along the grain (transversely) is relatively easy because this largely involves separating the longitudinal tracheids, using much less energy and producing a smoother fracture surface [18]. The variations shown in Figure 1 (E-C) partly support these assumptions.

Figure 1: Outdoor exposed surfaces of pine wood samples.

Another example of real-time urban furniture, three sitting units were prepared from the same wood species (pine wood), were found to be established to function in a park in Isparta city, Türkiye where those were placed at the same time but in different parts of the park.

Figure 2: Three sitting units are prepared from the same wooden material and established at the same time in a park. (A, E and I: Painted and aged moderately, B, C, D, E, F, G, H, J, K and L: Painted and aged severely).

All these were found to be brown colors painted against harsh atmospheric conditions when first placed in the park (Fig. 1A, E and I). But it is clearly seen that direct light-irradiated units (Fig. 2B, C, D, F, G, H, J, K and L) show an unpleasant appearance due to intensive light-induced peeling off, aging of paint layers, and distinct discoloration, while a sitting unit placed under a shelter appears to have only limited wear and aging (Fig. 2A).

As natural, unprotected wood is a biological material, it can be discolored by atmospheric factors and reacts chemically when it comes into contact with air [16]. Kotradyova et al. (2012) studied the influence of the color and texture of wood on the visual perception of observers by analyzing the color and texture of wood, separately. They found that the preference of the observers concerning the pure-generated wood color was much lower than the color and texture combined [19]. However, the effect of weathering on the aesthetic and physicochemical structure of wood has been extensively investigated by various researchers [10, 21-23]. Those changes could be evaluated visually or instrumentally. Hon and Minemura (2001) suggested that the discoloration of wood can be classified into five patterns visually, as determined during a 100-h light irradiation cycle. Those are darkening only, darkening and then fading, darkening-fading–darkening, fading only and fading and then darkening [13]. But there are many reports regarding problems with visual classification, which are usually correlated with the observer's emotions at that time [11,24,25]. In recent years, color changes of objects have been the focus of interest in utilizing highly precise spectrometry numeric methods to evaluate discoloration of materials, including wooden structures, with using relevant standards [6, 10, 23, 23-26].

The color coordinate properties of two different surfaces of the pine wood are shown in Table 1, comparatively. The control and weathered wood specimens demonstrated various values, depending on the measurement direction. It is notable that controls of tangent (T0) and radial (R0) specimens show only T-R(L*): 1.45 (metric) difference for lightness, T-R(a*): -0.07 (metric) for a* coordinate, and T-R(b*): -0.14 (metric) for b* coordinate. However, those values are marginally different between two surfaces, which could be negligible. Moreover, considerable discoloration was noted for outdoor exposure samples. It was found to be L_T(w-c): -9.93 (metric) and L_R(w-c): -8.54 lower from control L* coordinate values, b_T(w-c): :-4.02 and b_R(w-c): -0.66 lower from control b* color coordinate values for tangent and radial surfaces, respectively. For a* color coordinate, only a_T(w-c): 0.14 (metric) for tangent and a_R(w-c): 0.12 (metric) higher values were calculated.

Table 1: Color coordinate properties of specimens

	L*			a*			b*		
	c	**w**	**w-c**	**c**	**w**	**w-c**	**c**	**w**	**w-c**
T	69.74	59.81	**-9.93**	6.86	7	0.14	29.42	25.4	-4.02
R	68.29	59.75	**-8.54**	6.93	7.05	0.12	29.56	28.9	-0.66

Figure 3 shows the color coordinate differences of tangent and radial surfaces after weathering (Tw-Rw). It could be seen that negligible differences were found with L*(Tw-Rw): 0.06 (metric) and a*(Tw-Rw): -0.05 color coordinate, while a considerable difference is found for b*(Tw-Rw): -3.50 (metric) color coordinate. At the tangent surfaces, the lower b∗ values with weathering indicating a higher blue color intensity were readily apparent on that surface compared to the radial surface. It is worth noting that the L* and a∗ values did not change considerably between two surfaces, while a lowering in the b∗ values was observed with the tangent surfaces rather than radial surfaces.

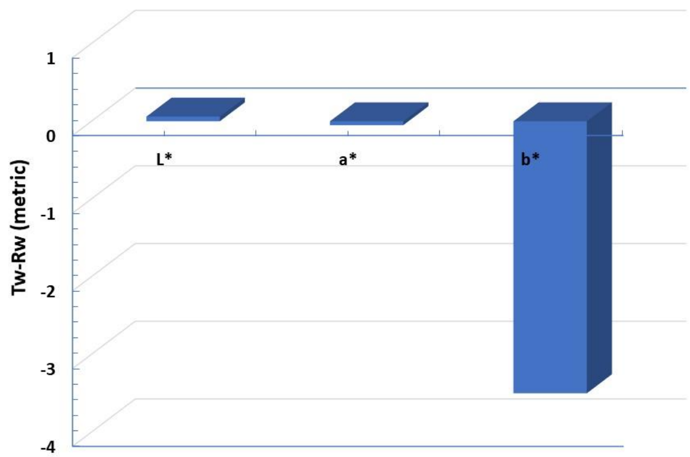

Figure 3: Color coordinate differences of specimens after weathering.

Total color changes of two surfaces were calculated, and the tangent surface showed higher discoloration properties than the radial surface (ΔE_T: 10.71 vs. ΔE_R: 8.57) after weathering. However, it appeared that lightness changes more than a* and b* coordinates after weathering, and lightness and the quantity of photo-induced discoloration show a strong relationship (in Table 1). It seems to have a higher-level discoloration (ΔE) on the tangent surface due to anatomical orientations, while opposite changes have been observed for the radial side of the same wood. Because original wood color is an important factor that strongly affects value, discoloration is a serious problem from the viewpoint of aesthetic worth and sustainability [10,11,23]. Moreover, one of the most confusing aspects of using wood for outdoor conditions is the way color associations change with time. It was proposed that the early-wood is more degradable by light radiation than late-wood, resulting in more early-wood discoloration than late-wood [13,16]. Those differences clearly impact the color variation of the two surfaces because of the different late-wood/early-wood differences between the two surfaces, as noted in our measurements. In addition, an ideal case, the relative discoloration of the different samples would be very similar within the same wood species and outdoor exposure, despite the differences in the initial color.

The C* (Chroma) and hue (h°) values of both tangent (Fig. 4A) and radial samples (Fig. 4B) were marked on a color circle and presented in Figure 4, comparatively. However, the Chroma differences were found to be only CT-CR: -0.15 (metric) and hue differences hT-hR: 0.07 (degree) between the tangent and radial surfaces of control samples. It could be suggested that there are negligible chromacity and hue value differences (<1.0 units) between the radial and tangent surfaces of the pine wood specimens. The weathered tangent surface shows a 3.86 (metric) lower chroma value (CT: 30.21 vs. CTw: 26.35), but the radial surface shows marginal differences (R0-Rw: -0.51). A similar trend was also found for hue values that tangent surfaces show hue values of hT: 76.87 (degree) and hTw: 74.59 (degree), and the 2.28 degree after lowering weathering, while only 0.57-degree lowering were found with the radial surface after weathering (hR: 76.80 vs. hRW: 76.23) (Fig. 4A and B).

One discoloration model is assumed to be applied to certain wood species and surface treatments. But the data obtained in the present study indicated that this behavior was rather a rough approximation. Because of its anatomical complexity, it is quite difficult to predict exact discoloration of pine wood, particularly after outdoor exposures.

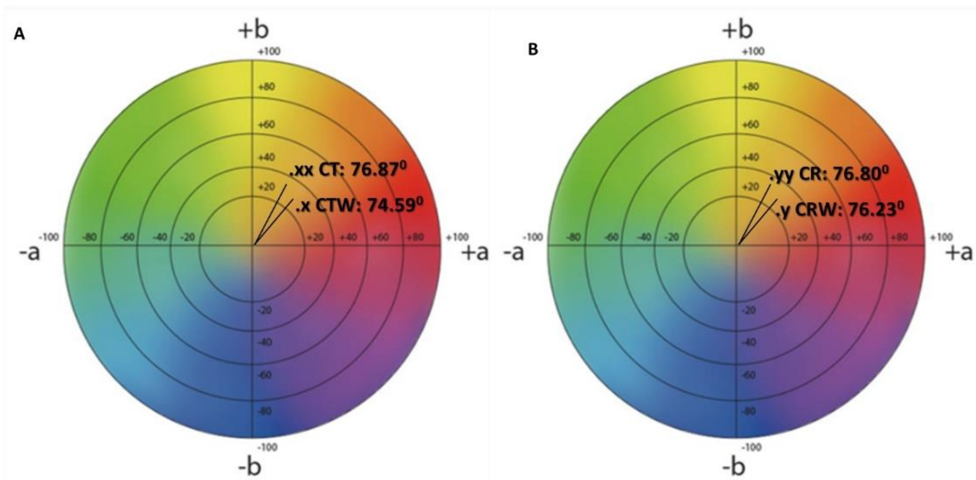

Figure 4: The chroma and hue properties of samples (A: tangent surface, B: radial surface).

Gloss is an optical property that is generally used to describe the visual appearance of an object. It is typically indicating how an object's surface reflects light in a specular (mirror-like) direction. It has been proposed by scientists that the surface topography of materials affects gloss [27-29]. Regarding this knowledge, we measured the gloss properties of two different surfaces initially and after the weathering process, as shown in Figure 5. There is only a 0.5 Gu difference between tangent and radial surfaces (T0: 6.6 Gu vs. R0: 7.1). After outdoor exposure, both surfaces show a lowering gloss value of ΔTC-W: -1.9 and $\Delta R_{C\text{-}W}$: -1.2 (Tw: 4.7 vs. Rw: 5.9). It is worth noting that those differences are not easily recognizable for observers due to all differences <3.0 Gu [30]. It could be reasonably suggested that there is no visually distinct gloss properties between two different surfaces for both the control and weathered samples.

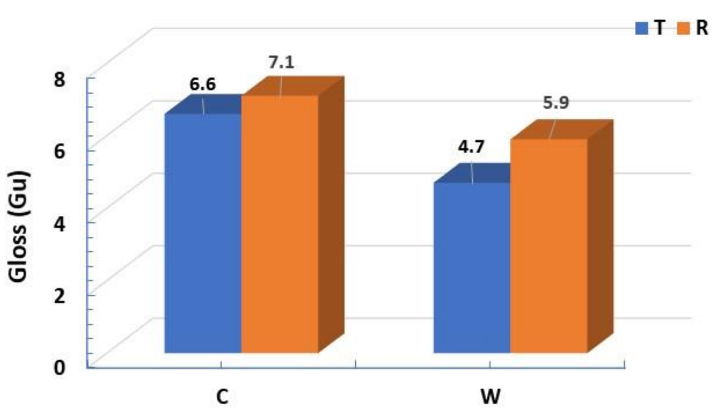

Figure 5: The gloss properties of specimens

The Yellowness Index (YI) is usually used to describe a change in unpigmented color from white or near-white samples toward yellow [31]. In wood science, it has already been reported by researchers that the yellowness color difference between a control and treated sample could be used to predict degradation levels of substrates such as; exposure to UV light or outdoor conditions that can cause chemical and physical changes (e.g., wood, plastic, or papers) that appear as yellow discoloration [24,31]. We believed that the yellowing may occur from outdoor exposure to wood specimens, which have complex photo-degradation reactions. Therefore, we are to calculate Yellowness values (reported as indices) for evaluating how two different wood surfaces respond under similar (weathering) conditions in terms of yellowness changes. Figure 6 shows the yellowness (index) color properties of control and weathered samples, comparatively. For control samples, a negligible yellowness difference value of -0.84 was found between both surfaces ($T0_{YI}$: 48.54 vs. $R0_{YI}$: 49.38; $\Delta YI_{T0\text{-}R0}$: -0.84). However, the radial surface showed a higher yellowness value than the tangent surfaces, which was found to be 52.70 (metric) for the radial surface and 47.62 (metric) for the tangent surface (Tw_{YI}: 47.62 vs. Rw_{YI}: 52.70; $\Delta YI_{T0\text{-}Tw}$: -0.92, $\Delta YI_{R0\text{-}Rw}$: 3.32). The positive (increased) values indicate the presence and magnitude of yellowness, while a negative yellowness value indicates that a material appears less yellow.

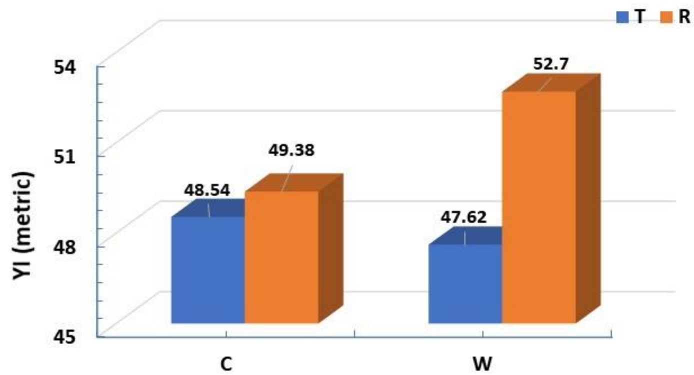

Figure 6: Yellowness (indices) properties of specimens

The CIE XYZ is another important color theory that is widely used to describe the color properties of objects. Using colors as perceived by human vision. Figure 6 shows the tristimulus properties of samples, comparatively.

For X stimuli (red color), initially only 2.03 (numeric) difference was found between radial and tangent surfaces (XT0: 41.85 vs. XR0: 39.82). However, after weathering, considerably lowering X stimuli values were found for both surfaces that it was ΔXTw-c: -12.68 (numeric) in tangent and ΔXRw-c: -10.67 (numeric) for radial surfaces.

Like X stimulu, almost similar trend was found with Y stimuli (yellow color) that, control samples only show 2.02 differences between radial and tangent surfaces (YT0: 40.38 vs. YR0: 38.36). After outdoor exposure, noticeable difference (lowering) Y stimuli values were found for both surfaces that it was ΔYTw-c: -12.47 (numeric) in tangent and ΔXRw-c: -10.46 (numeric) for radial surfaces.

For Z stimuli (blue color), it was found to be 24.54 and 22.92 for controls of tangent- and radial surfaces, where the difference between is only 1.62 (numeric). The outdoor exposure appeared to influence both surfaces negatively, lowering ΔZTw-c: -7.28 (numeric) for tangent and ΔZRw-c: -7.42 (numeric) for the radial surface, respectively.

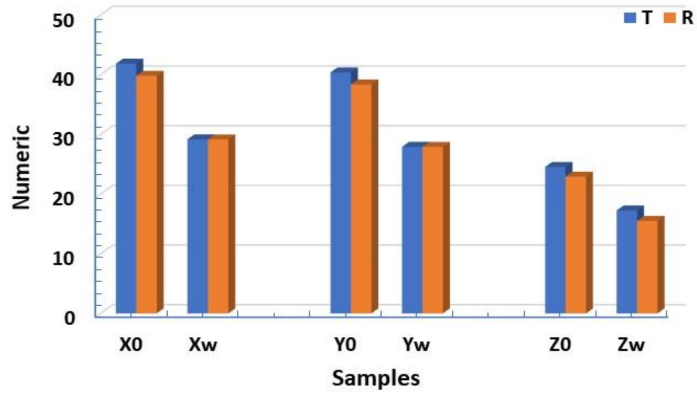

Figure 6: The CIE XYZ color properties of samples

CONCLUSION

The natural wood surface texture is responsible for the attractive appearance, which is especially the case for wooden architectural applications such as landscape elements, building structures, facades, and architectural practices. The anatomical differences could be seen between different families of woods (hardwood and softwood), but they also show differences within and among trees of the same species. Because of the complex anatomical arrangements, wood may be split, cracked, or discolored along the surfaces. It could be a very important issue for open space design practices, particularly urban furniture usage. In this regard, research conducted on Black pine wood species on tangent and radial surfaces after 6 months outdoor exposure to determine the effect of wood anisotropy for surface discolorations. However, modifications to the original wood color can be attributed to the photo-induced physicochemical reactions that take place for surfaces.

Color plays an important role, because the appearance of urban furniture evoked is influenced by its density or strength appearance. Softwood's anatomy is more simple, cheaper and constitute less cell types than hardwoods. Hence, in many wood-based architectural applications, the softwoods could be suggested for use rather than hardwood species.

References

[1] Şatır, S., & Korkmaz, E. (2005). Urban open spaces with examples and the classification of urban furniture. A| Z ITU Journal of the Faculty of Architecture, 2005. 2(01-02), 130-141.

[2] Satiroglu, E. Assessment of the Relationships Between Urban Furniture and Urban Spaces. Environmental Sustainability and Landscape Management. Bulgaria: St. Kliment Ohridski University Press Sofia, 2016. 694-702.

[3] Ulay, G., & Yeler, O. Wood and wood-based materials in urban furniture used in landscape design projects. Wood Industry and Engineering, 2020. 2(1), 35-44.

[4] Dascălu, D. M. Landscape Effects of Urban Furniture Textures. Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Horticulture, 2011. 68(1).

[5] Bolkaner, M. K., & Asilsoy, B. A study on urban furniture: Nicosia old city. European Journal of Sustainable Development, 2019. 8(2), 1-1.

[6] Sahin, C. K., & Onay, B. Alternative wood species for playgrounds wood from fruit trees. Wood Research, 2020. 65(1), 149-160.

[7] Winterbottom, D. M. Wood in the landscape: a practical guide to specification and design, 2000. (Vol. 2). John Wiley & Sons. NY.

[8] Kus Sahin, C., & Coskun, S. A Study on Leaching Properties of End-of-Life Tire for Urban Use Applications. European Journal of Applied Sciences, 2022. 10(5).494-503.

[9] De Nisco, A., & Warnaby, G. Urban design and tenant variety influences on consumers' emotions and approach behavior. Journal of Business Research, 2014. 67(2), 211-217.

[10] Sahin, C. K., Topay, M., & Var, A. A. A study on suitability of some wood species for landscape applications: surface color, hardness and roughness changes at outdoor conditions. Wood Research, 2020. 65(3), 395-404.

[11] Forsthuber, B., & Grüll, G. Prediction of wood surface discoloration for applications in the field of architecture. Wood science and technology, 2018. 52(4), 1093-1111.

[12] Fusaro, G., D'Alessandro, F., Baldinelli, G., & Kang, J. Design of urban furniture to enhance the soundscape: A case study. Building Acoustics, 2018. 25(1), 61-75.

[13] Hon DNS, Minemura N. Color and discoloration. In: Hon DNS, Shiraishi N (eds) Wood and cellulosic chemistry. 2001. Marcel Dekker, New York

[14] Oltean L, Teischinger A, Hansmann C (2008) Wood surface discolouration due to simulated indoor sunlight exposure. Eur J Wood Prod. 2008. 66(1):51.

[15] Şahin, C. An Analysis of Landscape Elements in Urban Detached House Gardens in Isparta City Center. Avrupa Bilim ve Teknoloji Dergisi,2020. (20), 566-571.

[16] Bowyer, J. L., Shmulsky, R., & Haygreen, J. G. Forest products and wood science. 2003. John Wiley & Sons. NY. 554p.

[17] Sahin, H. T. Wood-water interactions as affected by chemical constituents of woods. Asian Journal of Chemistry, 2008. 20(4), 3267.

[18] FPL. Wood as an engineering material. Forest Products Laboratory. Gen. Tech. Rep. FPL–GTR–113, 2010. USDA Product Society, Madison, Wisconsin, USA.

[19] Thuvander, F., & Berglund, L. A. In situ observations of fracture mechanisms for radial cracks in wood. Journal of materials science, 2000. 35, 6277-6283.

[20] Kotradyova, V., Teischinger, A., & Ebner, G. Aesthetic performance of different wood species: Visual interaction of human being and wood (by analyzing the colour and the texture of wood separately). Innovation in Woodworking Industry and Engineering Design, 2012. 1, 25-30.

[21] Pandey KK (2005) Study of the effect of photo-irradiation on the surface chemistry of wood. Polym Degrad Stab. 2005. 90(1):9–20.

[22] Gholamiyan, H., & Tarmina, A. The Effect of layers made off clear coats on the color changes and surface quality of wood after accelerated weathering in urban furniture. Iranian Journal of Wood and Paper Industries, 2019. 9(4), 561-574.

[23] Sahin, H. T., Arslan, M. B., Korkut, S., & Sahin, C. Colour Changes of Heat-Treated Woods of Red-Bud Maple, European Hophornbeam and Oak. Color Research & Application, 2011, 36.6: 462-466.

[24] Tolvaj, L., & Faix, O. Artificial ageing of wood monitored by DRIFT spectroscopy and CIE L* a* b* color measurements. 1. Effect of UV light, 1995. 49(5):397-404

[25] Wu, Y., Zhou, J., Huang, Q., Yang, F., Wang, Y., Liang, X., & Li, J. Study on the colorimetry properties of transparent wood prepared from six wood species. ACS omega, 2020. 5(4), 1782-1788.

[26] Mahy, M., Van Eycken, L., & Oosterlinck, A. Evaluation of uniform color spaces developed after the adoption of CIELAB and CIELUV. Color Research & Application, 1994. 19(2), 105-121.

[27] Badji, C., Soccalingame, L., Garay, H., Bergeret, A., & Bénézet, J. C. Influence of weathering on visual and surface aspect of wood plastic composites: Correlation approach with mechanical properties and microstructure. Polymer Degradation and Stability, 2017. 137, 162-172.

[28] Briones, V., Aguilera, J. M., & Brown, C. Effect of surface topography on color and gloss of chocolate samples. Journal of food engineering, 2006. 77(4), 776-783.

[29] Flys, O., Källberg, S., Ged, G., Silvestri, Z., & Rosén, B. G. Characterization of surface topography of a newly developed metrological gloss scale. Surface Topography: Metrology and Properties, 2015. 3(4), 045001.

[30] Zhou, F., Zhou, Y., Fu, Z., & Gao, X. Effects of density on colour and gloss variability changes of wood induced by heat treatment. Color Research & Application, 2021. 46(5), 1151-1160

[31] Sahin, H. T., & Mantanis, G. I. Colour changes in wood surfaces modified by a nanoparticulate based treatment. Wood research, 2011. 56(4), 525-532.

[32] ASTM E313-05. Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates. American Society for Testing and Materials Standard.