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Statistical Analysis of 19th Century Wooden Tile Parquet Hardness Test Results

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Abstract: *Statistical Analysis of 19th Century Wooden Tile Parquet Hardness Test Results.* In order to preserve wooden parquets from antique buildings located in South-Eastern Poland, we assessed their usage properties in accordance with the conservation doctrine from the Act on Monument Protection of 2003. The manor houses in Tarnowiec, Przewrotne and Falejówka had not been subject to renovation and their parquets are very well preserved in their original state. The presence of parquets based on different types of construction in several rooms of each manor house made it possible to collect numerous samples. Therefore, the risk of dependence of research results on the character of a random element is minimised and we are able to use objective statistical methods. Due to the variance of results between samples taken from the same batch of antique wood, the mean or the characteristic value might not be sufficient to represent its properties. For the above-mentioned reasons, statistical analysis was carried out in order to use the test results fully. The aim of the statistical analysis consisted in comparing the hardness of antique parquet wood (oak, ash, pine and elm) without finishes taken from the Tarnowiec, Falejówka and Przewrotne manor houses with contemporary wood of the same species; as well as in determining the significance of the species and of the sampling point (the manner of use and the climate conditions) for wood hardness. The hardness tests were carried out in accordance with the PN-EN 1534:2011 standard. Data analysis was performed with the GLM procedure from the SAS statistic package. The statistical analysis show that hardness of the samples under research depends on the wood species, the room and the sampling point (usage intensity and microclimate conditions).

Keywords: antique wooden parquet, resistance to abrasion, Tarnowiec, Falejówka and Przewrotne manor house

RESEARCH BACKGROUND

In order to preserve wooden parquets from antique buildings located in South-Eastern Poland, we assessed their usage properties in accordance with the conservation doctrine from the Act on Monument Protection of 2003. The fact that elements of wooden parquets have been preserved for almost 200 years shows that the wood quality was high.

The manor houses in Tarnowiec, Przewrotne and Falejówka had not been subject to renovation and their parquets are very well preserved in their original state. The presence of parquets based on different types of construction in several rooms of each manor house made it possible to collect numerous samples. Therefore, the risk of dependence of research results on the character of a random element is minimised and we are able to use objective statistical methods.

We tested samples of antique wood of different species, collected from different rooms and various sampling points, in comparison with various species of contemporary wood. The cluster analysis of FT-NIR test results shows a significant variance of sample properties (Fig. 1).

Variance between samples can be observed both within the same species of antique wood, e.g. oak, as well as when we compare it with contemporary oak. There are also major differences between the properties of wood samples collected from the same room, and the properties of wood taken from the internal corner of the room no. 1 in the Tarnowiec Manor House have such a big dispersion of results that sometimes they are similar to the properties of wood from the traffic paths and the external corner of that room. The same phenomenon occurs in case of antique elm from Room no. 5 of the Tarnowiec Manor House, and in this case the biggest dispersion of results is observed for samples taken from the traffic path. The smallest dispersion of test results characterises contemporary wood samples and antique wood samples from internal room corners.

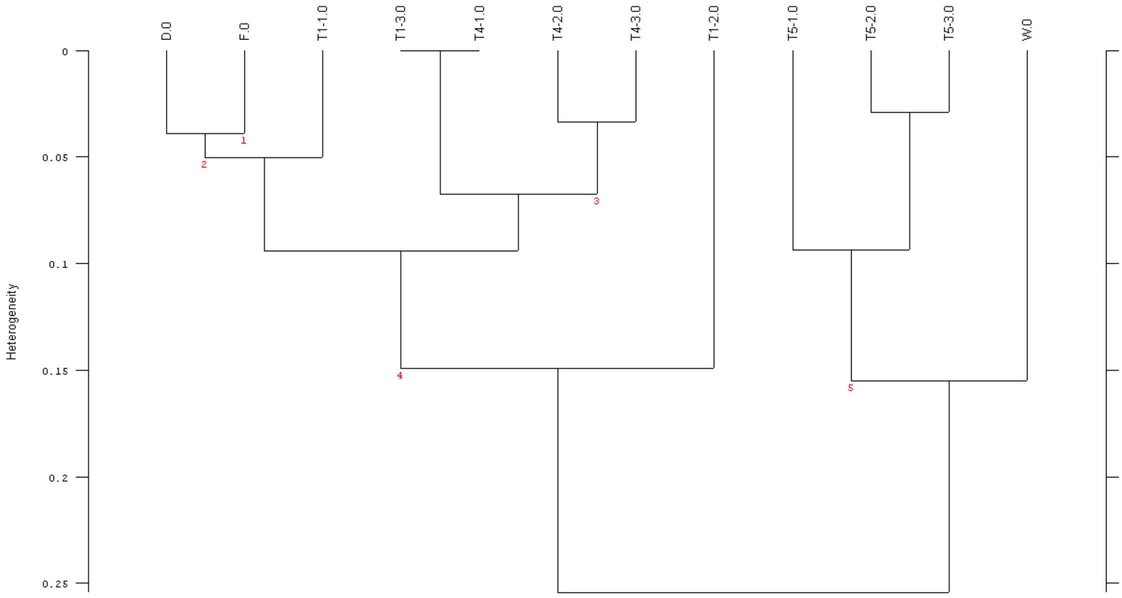


Fig.1. FT-NIR cluster analysis of all the collected samples - qualitative analysis of similarity with the use of Ward's algorithm and with the determination of the heterogeneity index (D – contemporary oak, F – oak Falejówka,
T1.1 – oak Tarnowiec room 1 point 1, T1.2 – oak Tarnowiec room 1 point 2, T1.3 – oak Tarnowiec room 1 point 3,
T4.1 – oak Tarnowiec room 4 point 1, T4.2 – oak Tarnowiec room 4 point 2, T4.3 – oak Tarnowiec room 4 point 3,
T5.1 – elm Tarnowiec room 5 point 1, T5.2 – elm Tarnowiec room 5 point 2, T5.3 – elm Tarnowiec room 5 point 3,
W – contemporary elm)

Due to the variance of results between samples taken from the same batch of antique wood, the mean or the characteristic value might not be sufficient to represent its properties. For the above-mentioned reasons, statistical analysis was carried out in order to use the test results fully.

AIM AND SCOPE OF RESEARCH

The aim of the statistical analysis consisted in comparing the hardness of antique parquet wood without finish taken from the Tarnowiec, Falejówka and Przewrotne manor houses with contemporary wood of the same species; as well as in determining the significance of the species and of the sampling point (the manner of use and the climate conditions) for wood hardness.

RESEARCH METHODOLOGY

The hardness tests were carried out on samples of antique and contemporary oak (*Quercus sp),* elm *(Ulmus sp),* ash *(Fraximus excelsior* L.) and pine wood (*Pinus sylvestris* L), size: 100x100 mm, thickness 2 mm, in accordance with the the PN-EN 1534:2011 standard. The measurements were made on the front side of the samples. The result was calculated as the average value of 8 repetitions. The antique elm wood samples were collected from Room number 5 in the Tarnowiec Manor House, antique oak from Rooms 1 and 4 in Tarnowiec and also from Falejówka, while pine and ash samples - from Przewrotne. Samples of elm and oak wood were collected from three sampling points: traffic paths as well as external and internal room corners.

The samples were acclimatized before the tests.

The hardness test results obtained in the experiment were presented graphically as an average with a standard deviation and characteristic value, and the data of hardness results for each sample were entered into the statistical software.

We assumed that the following factors have influence on wood hardness (AN): wood species (oak, ash, pine, elm) marked as E, room number (0, 1, 4, 5 in Tarnowiec, 6 in Przewrotne and 7 for contemporary wood) marked as C, as well as the location of parquet elements within the room - marked as D. The location of elements in the room determined the intensity of usage of a given element and the climate conditions around it. Samples were taken from three spots: traffic path, internal and external corner of the room. In the statistical analysis they were marked: traffic path, internal, external and general - when there was no possibility to select sampling points. The first three levels were distinguished for the sake of antique elements, because the location was considered an important factor for the variation of the property under research. The level called "general" refers to contemporary elements and elements from the Przewrotne manor house (where samples were taken from the entire room), because we decided that there is no need to divide them into three different manners of parquet use. Therefore, the location of parquet elements in a room reflects the climate conditions that surrounded the wood. They might be different in different rooms, so each level of the factor D, for example the level of "traffic path", in spite of the same name, can refer to different climate conditions. For this reason, we assumed that the factor D was hierarchically placed within the factor C (D was nested in C).

Due to the fact that the tested material has a historical, patrimonial value, and due to the limitations related with this fact, the classification of the data gathered was not orthogonal and it is not possible to estimate the potential interactions between the factors. For this reason, data analysis was performed with the GLM procedure from the SAS statistic package.

The formal equation of the statistical model in this experiment was assumed as follows:

$AN_{ijk} = \mu + \alpha_i + \beta_j + \gamma(\beta)_{k(j)} + \varepsilon_{ijkl}$, where:

μ - the base, on which the effects of the tested factors were calculated,
α_i - the effect of the i-wood species
β_j - the effect of the j-room,
$\gamma(\beta)_{k(j)}$ – the effect of the k-climate in the j-room
ε_{ijkl} - the experiment error (errors of measurement + diversity of parquet planks)
AN_{ijk} - the hardness value in the l-sample made of the i-wood species taken from the j-room and used with k-intensity.

A simplified form of this statistical model can be presented as follows: AN=E+C+D(C)+error, where the E, C, D factors are constant.

It was assumed that the errors $\{\varepsilon_{ijkl}\}_{ijkl}$ are independent random variables with the same distribution $N(0,\sigma^2)$ [normal distribution with the average 0 and variance σ^2]. Due to the fact that we analysed 4 wood species, the index "i" had 4 values. Samples were taken from rooms 1, 4, 5, 6 and 7, so the index "j" had 5 values. The indices "k(j)" have from 2 to 3 values for different "j". The index "l" has values from 6 to 42, depending on "i", "j" and "k", due to the limitations concerning the possibility to collect samples (the classification of the data gathered is not orthogonal). The number of observations differs for different rooms, wood species and sampling points (Table 1).

Tab.1. Values of the index "l" (number of observations)

D	E	C					
		0	1	4	5	6	7
traffic paths	oak		33	42			

	elm				40		
general	oak	10					10
	ash					10	6
	pine					10	6
	elm						10
internal	oak		10	40			
	elm				39		
external	oak		10	39			
	elm				32		

Considering that the parameters μ, α_i, β_j, $\gamma(\beta)_{k(j)}$ cannot be determined clearly within the assumed model, they were determined automatically in the GLM procedure of the SAS package. In practice, it means that some parameters are compared with zero. Although statistical theory offers other ways of introducing parameter limitations (e.g. the sum of effects of a given factor must equal zero), the manner of their introduction does not influence the estimation of average values nor the detailed comparisons.

The SAS statistical package verified 3 main hypotheses: 1) hardness does not depend on wood species, which means that the factor E does not influence the property under research (AN),

2) hardness does not depend on the room, which means that the factor C does not influence the property under research (AN),

3) hardness does not depend on the climate, which means that the factor D(C) does not influence the property under research (AN) for chosen significance level 0.0. If a given hypothesis was discarded, the Tukey-Kramer procedure was carried out to make detailed comparisons for the factor in question - least squares means.

Considering that in the research there were different wood species and sampling points (rooms and climate), for antique oak and elm we assumed an additional factor that identified each sample batch unambiguously - CDE, and antique wood was compared to the appropriate contemporary wood species. We used the ANOVA procedure when analysing the factor's significance and Dunnett's T tests for detailed comparisons.

TEST RESULTS AND STATISTICAL ANALISIS

The test results are presented graphically on Figure 2.

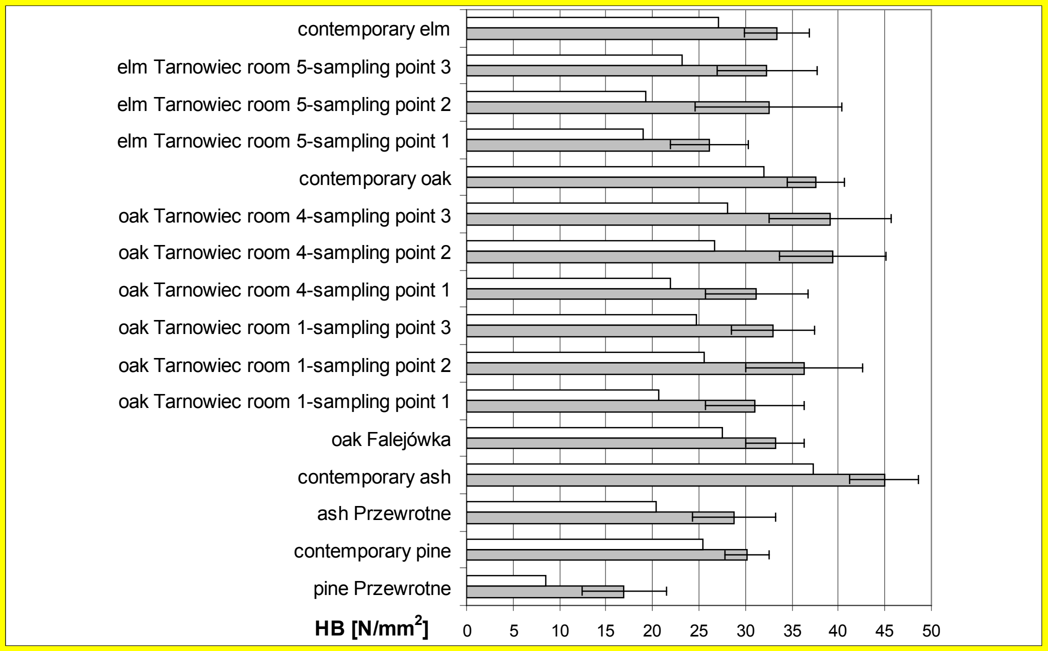


Fig.2. Hardness testing with the use of the Brinell method together with characteristic value □ (samples taken from sampling point 1 - external room corner; sampling point 2 - traffic paths; sampling point 3 - internal room corner)

The verification of the three hypotheses in statistical analysis showed that all the factors included in the model have a significant influence on the property under research.

Detailed comparisons as to the wood species (factor E) prove that among the species under research ash is significantly different from pine and elm. It is much harder. There is no significant difference between the hardness of ash and oak (Fig.3a).

Detailed comparisons concerning rooms (factor C, Fig.3b) show that Room no. 6 (that is: the Przewrotne Manor House) is clearly different from the rest, which means that the parquet made of pine and ash has lower hardness. In the room number 4 (oak - Tarnowiec Room 4) the oak wood is harder than in the room number 1 (oak - Tarnowiec Room 1). There are no significant differences between the remaining rooms as far as the wood hardness is concerned. The highest wood hardness has been observed for “room” number 7, that is for the averaged wood of contemporary pine, ash, oak and elm.

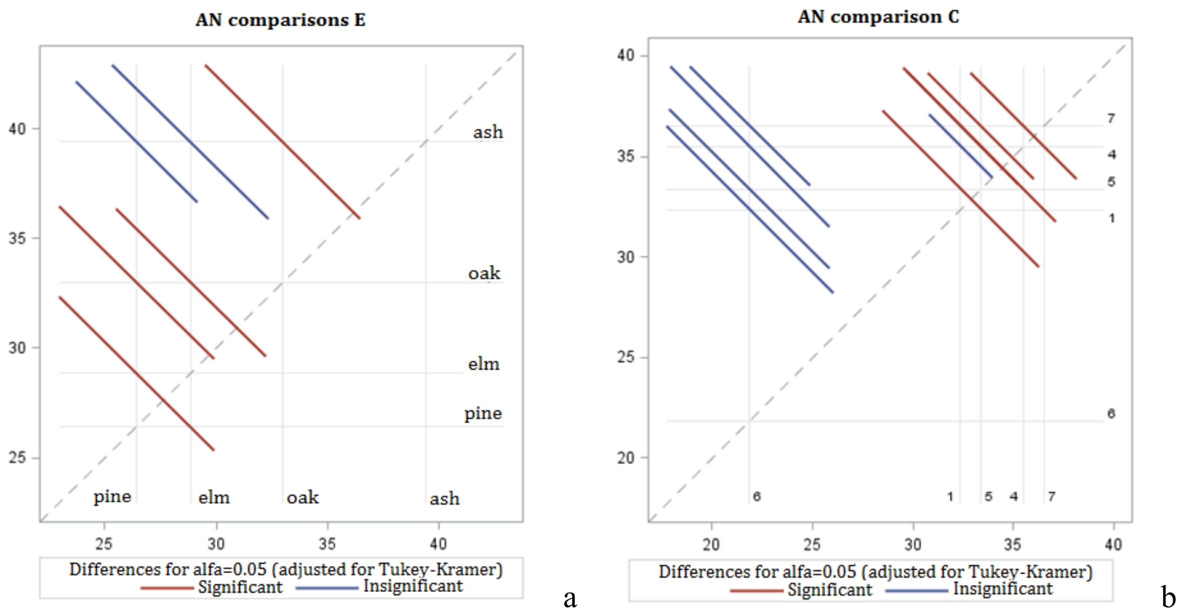


Fig. 3. Hardness comparison for different wood species (a) and rooms (b)

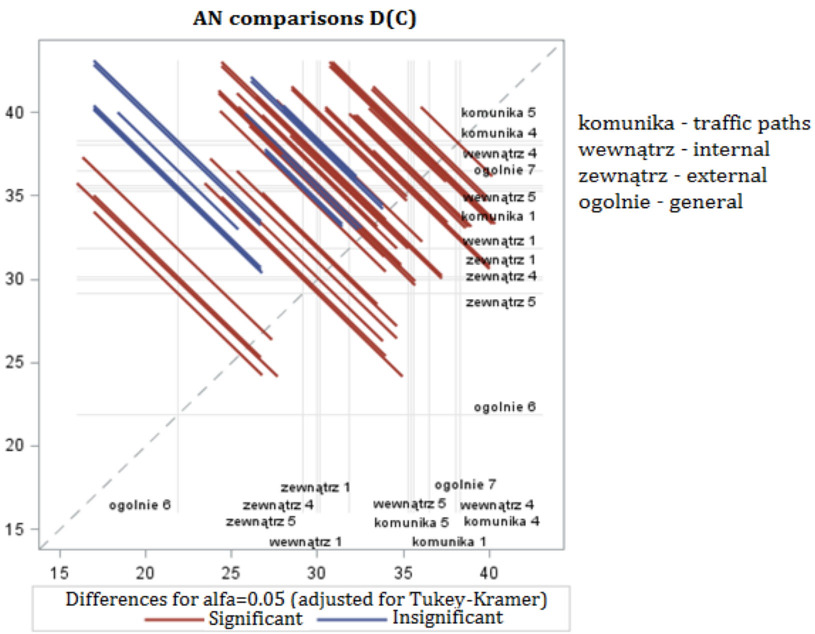


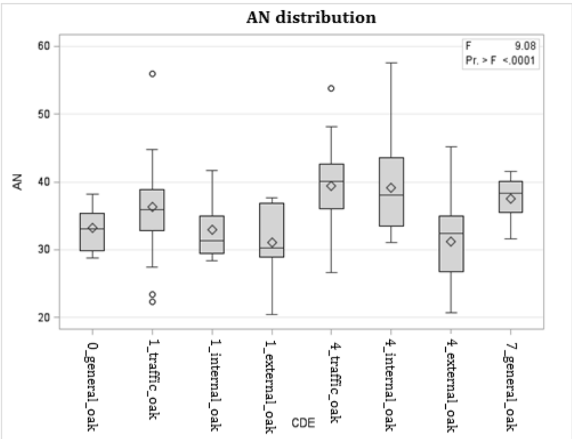
Fig.4. Hardness comparison for different climates

Detailed comparisons concerning the climate (D(C)) show that in Room no. 1 (oak - Tarnowiec Room 1) there are no statistically significant differences in relation to climate (that is: depending on the sampling point). In room 4 (oak - Tarnowiec Room 4) the external climate (external room corner) is significantly different from the rest. Similarly, in room number 5 (elm - Tarnowiec Room 5) the external climate (external room corner) is significantly different from the rest. The predominance of red lines on the chart (Fig. 4) shows that there are no significant differences between most of the rooms. Room no. 6 (pine and ash from the Przewrotne Manor House) shows statistically significant differences, most of all with the climates “traffic path” and "internal” of the Rooms 4 and 5 in Tarnowiec (the hardness of samples taken from traffic paths and internal room corners), while there are no differences comparing with the external climate (hardness of samples taken from external room corners) both for oak and for elm.

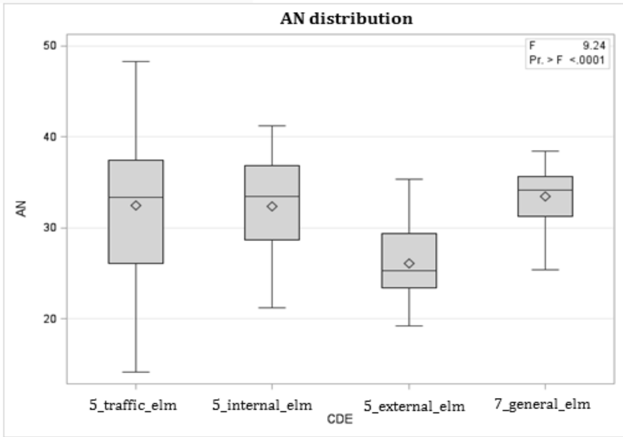
Additionally, we analysed the mean hardness taking into account the CDE factor for all the antique oaks and antique elms comparing with contemporary oak and elm.

The analysis carried out for oaks has shown that when considering the mean hardness for all antique oaks in comparison with contemporary wood, the CDE factor is indeed significant, yet the only statistically significant difference occurred for the oak collected from the external corner of the room number 4 in the Tarnowiec Manor House (Fig. 5a).

Similarly, the analysis of mean hardness for the CDE factor for all the antique elms compared with contemporary elm has proven that the factor is significant, but statistically significant differences between the mean hardness of contemporary and antique elm appear only in case of samples taken from the external corner of Room no. 5 in the Tarnowiec Manor House (Fig. 5b).



a



b

Fig. 5. Mean hardness analysis taking into account the CDE factor: a - for all the antique oaks compared with contemporary oak (0 - antique oak from Falejówka, 1 - antique oak from Room 1 in Tarnowiec, 4 - antique oak from Room 4 in Tarnowiec, 7 - contemporary oak), b - for all the antique elms compared with contemporary elm (5 - antique elm from Room 5 in Tarnowiec, 7 - contemporary elm)

CONCLUSIONS

1. The hardness of the samples under research depends on the wood species, the room and the sampling point (usage intensity and microclimate conditions).
2. The highest hardness has been observed for ash, whose hardness is not significantly different from oak, but it differs from elm and pine.
3. In spite of the fact that ash was the hardest wood, the hardness of the parquet from the Przewrotne Manor House (made of ash and pine wood) is smaller than the hardness of oak and elm parquets.
4. There are no statistically significant differences between the hardness of Tarnowiec parquets made of elm and oak, except for the oak parquet from Room no. 1 of the Tarnowiec Manor House, which is significantly lower.
5. The lowest hardness has been observed in the case of samples taken from external room corners, and they are significantly different from the comparable hardnesses of samples collected in internal room corners and traffic paths (except for Room no. 1 in the Tarnowiec Manor House).
6. The hardness of the ash-and-pine parquet from Przewrotne is comparable with the hardness of oak and elm parquet from the external room corner.
7. The hardness of contemporary wood is in general higher than the hardness of antique wood, but the differences between the hardness of antique wood from Room no. 4 and antique elm from Room no. 5 in comparison with the corresponding contemporary wood species are significant only in case of samples taken from external room corners.

Streszczenie: *Statystyczne opracowanie wyników badań twardości drewna dziewiętnastowiecznych posadzek taflowych.* Ocena właściwości użytkowych drewnianych posadzek pochodzących z obiektów zabytkowych znajdujących się w Południowo-wschodniej Polsce w celu ich zachowania zgodna jest z przyjętą doktryną konserwatorską, zawartą w Ustawie o Ochronie Zabytków z 2003r. Zachowanie się przez blisko 200 lat elementów drewnianych posadzek zabytkowych świadczy o wysokiej jakości zastosowanego drewna. Dwory w Tarnowcu, Przewrotnem i Falejówce nie poddawane wcześniejszym zabiegom konserwacyjnym mają znakomicie zachowane posadzki, których stan jest oryginalny. Istnienie posadzek opartych na różnych typach konstrukcji w kilku pomieszczeniach każdego dworu zapewnia możliwość pobrania licznych próbek. W ten sposób minimalizuje się niebezpieczeństwo uzależnienia wyników badań od charakteru przypadkowo wybranego elementu oraz daje możliwość zastosowania obiektywnych metod statystycznych. Ze względu na zróżnicowanie wyników pomiędzy próbkami tej samej partii w przypadku drewna zabytkowego, średnia z odchyleniem standardowym czy wartość charakterystyczna mogły w niedostateczny sposób charakteryzować jego właściwości. Z powyższych względów dla pełnego wykorzystania otrzymanych wyników badań przeprowadzono analizę statystyczną. Celem analizy statystycznej było porównanie twardości niewykończonego drewna zabytkowych posadzek dworów w Tarnowcu, Falejówce i Przewrotnem ze współczesnym drewnem analogicznych gatunków oraz określenie istotności wpływy czynników gatunku drewna oraz miejsca pobrania (sposób użytkowania oraz warunki klimatyczne w jakich przebywało drewno próbek) na twardość drewna. Badania twardości wykonano zgodnie z normą PN-EN 1534:2011. Do analizy danych wybrano procedurę GLM pakietu statystycznego SAS. Statystyczna analiza wykazała, iż twardość badanych próbek zależy od czynnika gatunku drewna, pomieszczenia i miejsca pobrania próbek (przekładającą się na intensywności użytkowania i warunki mikroklimatyczne).

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