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

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Abstract: *Statistical Analysis of 19th Century Wooden Tile Parquet Abrasion 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 fact that elements of wooden parquets have been preserved for almost 200 years shows that the wood quality was high. The aim of the analysis is to compare oak, ash, pine and elm samples of wooden elements without finish collected from parquets in the Tarnowiec, Falejówka and Przewrotne manor houses and contemporary parquet materials made of solid wood, taking into account the abrasion wear measured by mass loss. Another purpose of the analysis is to specify the significance of factors such as wood species and climate for the wood's resistance to abrasion. The abrasion resistance was measured with the Taber method on the basis of mass loss, in accordance with PN-EN ISO 5470-1:2001 standard. The test results obtained in the experiment were presented as an average with a standard deviation, but considering the above-mentioned variance of results between samples from the same batch, they might not be enough to characterise the antique wood properties properly. This is why we used statistical analysis performed with the GLM procedure of the SAS statistic package. The statistical analysis show, that abrasive wear of the samples under research measured by mass loss depends on the following factors: wood species, room and sampling point (usage intensity and microclimate conditions).

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

AIM AND SCOPE OF RESEARCH

The aim of the analysis is to compare samples of wooden elements without finish collected from parquets in the Tarnowiec, Falejówka and Przewrotne manor houses and contemporary parquet materials made of solid wood, taking into account the abrasion wear measured by mass loss. Another purpose of the analysis is to specify the significance of factors such as wood species and climate for the wood's resistance to abrasion.

We assumed the following symbols for the corresponding factors: wood species (oak, ash, pine, elm) marked as E, room number (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. We assumed the following names for the categories: traffic paths (for samples taken from traffic paths), internal (for samples taken from internal room corners), external (for samples taken from external room corners) and general (if there was no possibility to take samples from the 3 sampling points in a given room). The first three levels were distinguished for oak and elm wood from the Tarnowiec Manor House, because we considered that this factor can be important for the variation of the property under research. The level called "general" refers to contemporary elements and elements from the Przewrotne manor house, because we decided that there was no need to divide them into three different manners of usage.

Similarly as in the case of hardness tests result analysis, we assumed that the location of parquet elements in a room reflects the climate conditions that surrounded the wood. Considering that they can be different for each room, and each level of the D factor can in fact signify another climate, we assumed that the factor D was hierarchically placed within the factor C (D was nested in C).

RESEARCH METHODOLOGY

The abrasion resistance 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 PN-EN ISO 5470-1:2001 standard. The abrasion resistance was measured with the Taber method. The result was the value of mass loss for each sample. 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 test results obtained in the experiment were presented as an average with a standard deviation and characteristic value, but considering the above-mentioned variance of results between samples from the same batch, they might not be enough to characterise the antique wood properties properly. This is why we used statistical analysis.

Statistical analysis was performed with the GLM procedure of the SAS statistic package. The formal equation of the statistical model was assumed as follows:

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

Y_{ijk} – the value of mass loss in the l-sample made of 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: Y=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 43, depending on "i", "j" and "k", due to the limitations concerning the possibility to collect samples (the classification of the collected data 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		10	40			
	elm				40		
general	oak	10					10
	ash					10	6
	pine					10	6
	elm						10
internal	oak		10	40			
	elm				39		
external	oak		10	43			
	elm				32		

Similarly as in the case of the statistical analysis carried out for hardness tests, and considering that the parameters μ, α_i, β_j, $\gamma(\beta)_{k(j)}$ cannot be determined clearly in this 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 the 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.

First of all, the SAS statistical package verified 3 main hypotheses:

1) mass loss does not depend on the wood species, which means that the factor E does not influence the property under research (Y),

2) mass loss does not depend on the room, which means that the factor C does not influence the property under research (Y),

3) mass loss does not depend on the climate, which means that the factor D(C) does not influence the property Y under research for the chosen significance level 0.05.

If a given hypothesis was discarded, the Tukey-Kramer procedure was carried out to make detailed comparisons for the factor in question.

Moreover, for antique oak and elm we assumed an additional factor that identified each sample batch unambiguously - CDE. It was necessary because of the variance of the tested wood species and sampling points (rooms and climate). In this way, the antique oak and elm wood from each location of each room was compared with the appropriate contemporary wood species. We used the ANOVA procedure to analyse the factor's significance and Dunnett's T tests for detailed comparisons.

The level of significance was specified at the level of 0.05.

TEST RESULTS AND STATISTICAL ANALISIS

We determined the average value of the obtained test results and calculated the standard deviation - the data was presented graphically on Figure 1.
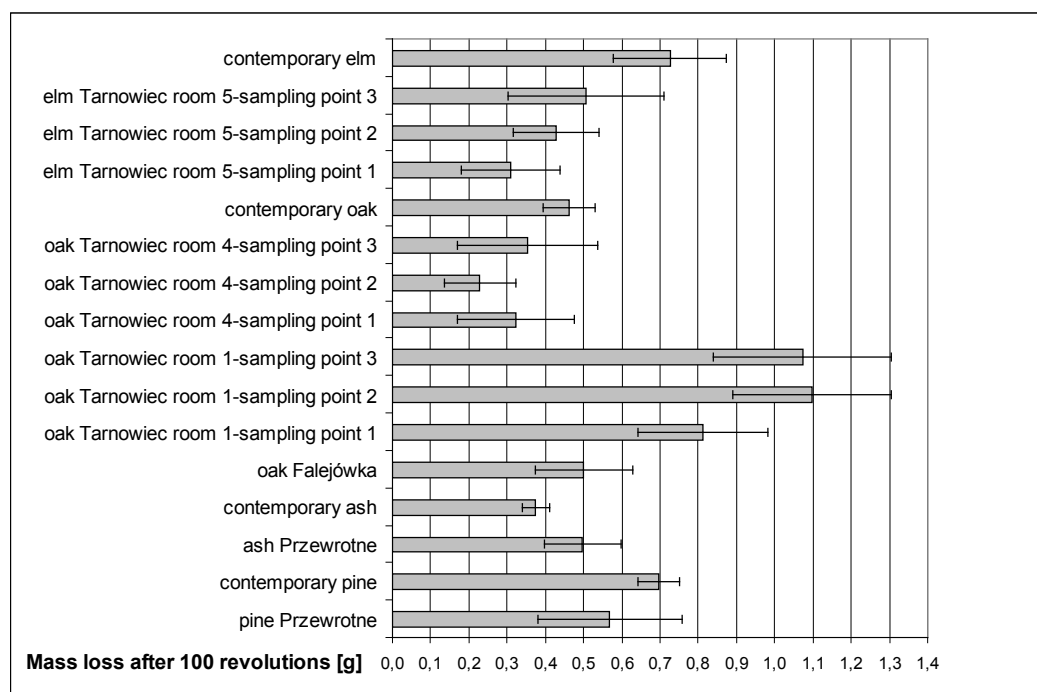

Fig.1. Abrasion wear tests - mass loss (samples taken from: sampling point 1 - external room corner; sampling point 2 -traffic paths; sampling point 3 - internal room corner)

The statistical analyses that were carried out proved that the mass loss at the level of significance of 0.05 depends on the wood species, room and climate factors.

The average mass loss for each wood species (factor E) was analysed through all the levels of the remaining factors. The biggest mass loss occurred in elm wood samples, and then in the following order: pine, oak and ash wood. The only differences that were statistically significant were the differences between: oak and elm, oak and pine, ash and elm, and ash and pine. (Fig.2a). Therefore, we have two uniform groups that are different from one another: {oak, ash}, {elm, pine}. The biggest mass losses occurred in case of elm and pine.

Fig.2 Average mass loss for each wood species (a) and average mass loss in the rooms (b)

Fig.3. Average mass loss in relation to the climate

The statistical analysis of the average mass loss in the rooms (factor C) revealed that the rooms: 4 (oak - Tarnowiec Room 4) and 5 (elm - Tarnowiec Room 5) are not significantly

different (Fig.2b). There are differences between the remaining rooms. Uniform groups: {4,5}<{7}<{1}. The biggest mass losses occurred in room 1 (oak - Tarnowiec Room 1), then for different contemporary wood species described as "Room 7" (contemporary wood), while the smallest in rooms 4 and 5 (oak and elm from Rooms 4 and 5 in the Tarnowiec Manor House).

Moreover, we analysed the average mass loss in relation to the climate (D(C), Fig 3). This chart shows the details of statistical differences between the respective averages.

In general, it should be noted that Room 1 (oak - Tarnowiec Room 1) is clearly different from the remaining rooms and there is a big variance in that room as far as the property under research is concerned (almost only blue lines). Only the "traffic paths" climate (samples taken from the part of the parquet in the room that was used for traffic - where people walked) and "internal" (samples taken from internal room corner) are not significantly different from one another.

In case of the remaining rooms the image is not that clear. In the Room number 4 of the Tarnowiec Manor House, oak from the "external" climate (samples taken from external room corners) does not differ from the internal room corners and communication paths. Similarly, in case of elm from Room no. 5 in Tarnowiec, there are no significant differences between the "internal" and "traffic path" climates.

In general (considering rooms 4 and 5), room number 5 (elm - Tarnowiec Room 5) with the "external" climate is different from the rest. In the remaining cases there are rather no differences. The "Room 7" signifying all the species of contemporary wood is interesting; it is different from oak of all the climates from Room no. 1 and from the "traffic path" climate from Room number 4 in Tarnowiec. Contemporary wood is also different from elm wood of all the possible climates.

The mass losses of averaged contemporary wood compared with rooms 4 (oak - Tarnowiec Room 4) and 5 (elm - Tarnowiec Room 5) in general are higher and they are not significantly different from the "internal" and "external" climates of the Room number 4 in the Tarnowiec Manor House. The highest mass losses have been observed in case of oak from the Room number 1 in the Tarnowiec Manor House, they are higher and significantly different from the averaged wood of contemporary pine, ash, elm and oak.

The analysis of the mean mass loss in relation with the CDE factor for all the antique oaks compared with contemporary oak has revealed that the CDE factor is significant, but the mean mass loss of antique oaks in relation with the CDE factor compared with the mean mass loss of contemporary oak is statistically significant only for all the climates of oak samples from Room no. 1 in Tarnowiec and for oak from the traffic path from Room no. 4 (Fig.4a). In case of oak from the Falejówka manor house and oak from Room no. 4 of the Tarnowiec Manor House collected from internal and external room corners, the differences are not statistically significant.
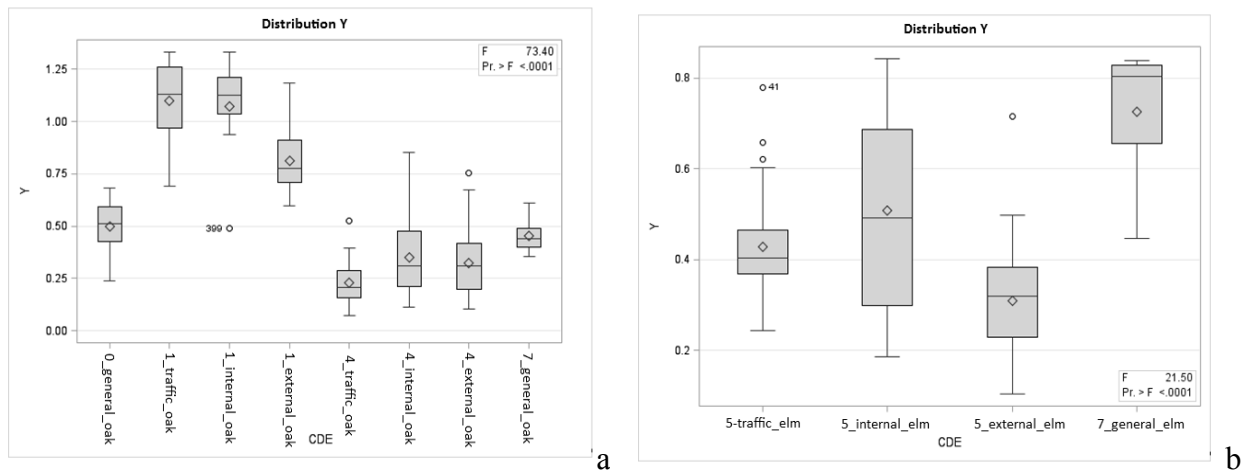
Fig. 4. Mean mass loss analysis taking into account the CDE factor: a - for all the antique oaks compared with contemporary oak (0 - antique oak from Falejówka, 1 - antique oak from Room 1 in Tarnowiec, 4 - antique oak from Room 4 in Tarnowiec, 7 - contemporary oak), b - for all the antique elms compared with contemporary elm (5 - antique elm from Room 5 in Tarnowiec, 7 - contemporary elm)

The analysis of the mean mass loss in relation with the CDE factor for all the antique elms compared with contemporary elm has revealed that the above-mentioned factor is significant, and the mass differences between antique and contemporary wood are significant for all the antique elms (Fig.4b).

CONCLUSIONS
1. The abrasive wear of the samples under research measured by mass loss depends on the following factors: wood species, room and sampling point (usage intensity and microclimate conditions).
2. Elm and pine have significantly lower resistance to abrasion than oak and ash, and their resistance is similar to one another (there are no statistically significant differences), similarly as it is in the case of oak and ash.
3. The smallest resistance to abrasion has been observed for antique oak from Room no. 1 in the Tarnowiec Manor House. The resistance of antique oak from Room no. 4 and elm from Room no. 5 in Tarnowiec is comparable (no statistically significant differences) and it is bigger even than the resistance of contemporary wood.
4. The smallest resistance to abrasion has been observed in the case of samples taken from external room corners; while the samples collected from traffic paths and internal room corners are comparable (there are no statistically significant differences).
5. The abrasion wear of antique elm is significantly bigger, and that of antique oak is comparable with the corresponding contemporary wood species, except for oak from Room no. 1 in Tarnowiec, which has a significantly lower abrasion resistance than contemporary oak.

Streszczenie: *Statystyczne opracowanie wyników badań odporności na ścieranie drewna dziewiętnastowiecznych posadzek taflowych.* Celem analizy jest porównanie próbek niewykończonych elementów pozyskanych z posadzek pochodzących z dworów w Tarnowcu, Falejówce i Przewrotnem oraz współczesnych materiałów posadzkarskich wykonanych z drewna litego ze względu na ścieralność mierzoną ubytkiem masy. Analiza ma także na celu określenie istotności wpływu czynników gatunku drewna, pomieszczenia oraz klimatu na odporność na ścieranie drewna. Uzyskane w doświadczeniu wyniki badań zostały przedstawione jako średnia z odchyleniem standardowym oraz wartość charakterystyczna, jednak ze względu na zróżnicowanie wyników pomiędzy próbkami tej samej partii mogły one w niedostateczny sposób charakteryzować właściwości drewna zabytkowego. Dlatego odwołano się do analizy statystycznej z zastosowaniem procedury GLM pakietu statystycznego SAS. Analizy wykazały, iż ścieralność badanych próbek mierzona ubytkiem masy zależy od czynnika gatunku drewna, pomieszczenia i miejsca pobrania próbek (przekładających się na intensywności użytkowania i warunki mikroklimatyczne).

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