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Analysis of the Chair's Comfort Before and After Renovation

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Furniture is an object that accompanies us in everyday life. Therefore, it is important to choose appropriate dimensions, tailored to the human body, which will ensure comfort during use. Due to the noticeable gradual wear and tear of furniture or its components, these products are renewed and renovated. Both external and internal damages are reflected not only in the subjective feelings of furniture users but also in objective studies showing comfort coefficients in numerical values. The main objective of this study was to compare the comfort of use of two AGA chairs before and after renovation. The objective was achieved by examining the comfort of use for the seat and backrest of both chairs using a sensor mat.

The comparison was made based on the results of the tests, which were obtained in the form of color maps of stress distributions, SPD and D coefficients. For the first chair, the original layout was used, the same as in the chair before renovation, with the use of new materials. In the second chair, the upholstery layout was changed in relation to the original. Based on the results obtained, it was noted that during the renovation of used chairs, restoring their original structure results in improved utility properties. However, any changes to the structure that differ from the original upholstery layout may result in the failure to restore the initial level of comfort.

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Introduction

Furniture is considered to be utility equipment that is used for sitting, lying down, working, storing and eating meals (Swaczyna, Swaczyna 1993; Dzięgielewski, Smardzewski 1995). They are an inseparable element in the life of a person who is a creative being, and it is thanks to them that so many pieces of furniture in the world around us have been created. As humans began to secure their basic necessities more easily, they started focusing on products to improve the quality of life. One such product is the comfort chair—designed specifically for individuals who need to remain seated for extended periods, whether for work or daily activities (Patil et al. 2022). The continuous development of techniques and technologies has resulted in more and more furniture products being manufactured and available to almost everyone immediately. The furniture industry is constantly developing all over the world. Not only is the number of stores increasing, but also the variety of products they offer. Nowadays, furniture can be purchased for a small amount of money, which

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allows for frequent replacement. Unfortunately, the low price is usually reflected in the quality of workmanship and materials from which the product was made. The opposite situation occurred in the second half of the 20th century and in earlier years. Furniture products purchased at that time often served for years, some still do today, and are also passed down from generation to generation. In recent years, we can observe that furniture from the 20th century is coming back into favor (Lange et al. 2025). Many people have begun to appreciate its uniqueness, from design to quality. It is true that the everyday equipment that we use, which is 40 or 50 years old, is damaged to some extent, and the degree of its wear is clearly noticeable. Despite this, it is still suitable for use; sometimes it is only necessary to refresh it, clean it, and replace the damaged materials. Many such pieces of furniture can be purchased for a small amount of money on auction portals, various bazaars and can also be found near garbage bins or on the streets during bulky waste collection. The ever-increasing trend of furniture renovation and restoration is influenced by society's growing environmental and consumer awareness. Many people are trying to limit the growth of consumerism, want to repair damaged things and objects, and not replace them with new ones. Among furniture, one can observe their great diversity, not only due to visual aspects and materials from which they are made, but also due to functions.

Seating furniture such as chairs, armchairs, sofas, couches, and sofa beds usually belongs to the group of upholstered furniture. Their construction is quite complex due to the way the upholstery systems are made, i.e., parts that are made of soft, elastic materials or a combination of both (Swaczyna, Swaczyna 1993). An integral part of upholstered furniture is the covering layer, which consists of cut material formats connected by sewing into a cover (Lange et al. 2022).

Smardzewski (2018), in his book, uses the criterion of seat or mattress softness to divide upholstered furniture into soft, semi-soft, and hard. The author states that such a division is a subjective matter and, in many situations, depends on the personal impression (concerning the softness of the seat) of the person who designs a given piece of furniture. He also adds that in order to adopt a more objective division regarding the assessment of the softness of products, it is important to determine the value of the maximum possible pressure of the mattress or seat at contact with the human body. On the other hand, Dzięgielewski, Smardzewski (1995) point out that the softness of upholstered products should be determined based on physiologists' guidelines, because seating furniture should ensure a free positioning of the spine, proper blood flow, and muscle relaxation. Fulfilling the above conditions will have an impact on healthy rest.

In the literature, a lot of attention is paid to issues related to the analysis of the selection and modeling of rigidity of seats made of traditional foams (Linder-Ganz et al. 2005; Schrodt et al. 2005; Vlaovic et al. 2008; Grujicic et al. 2009; Lusiak and Smardzewski 2010; Silber et al. 2010; Smardzewski et al. 2010a, 2010b; Wiaderek and Smardzewski 2010a, 2010b; Smardzewski and Matwiej 2013; Wiaderek et al. 2016) as well as impact determination of long-term use of selected constructions of upholstered furniture seats for rest on the quality of use (Wiaderek et al. 2019).

Grandjean (1978) describes the sitting position as a natural body position, thanks to which the work of the leg, hip, and back muscles is reduced and relaxed, and seats should be designed in such a way as to reduce the pressure on the intervertebral discs while the user is in a sitting position. Matwiej (2011) points out that when the user feels discomfort while using the furniture, in order to improve their sensations, they involuntarily change the position of their body. Important information in this matter is that such situations are influenced by the closure of the smallest blood vessels (so-called capillaries), which occurs after reaching the local limit value of pressure, which is 28-45 mmHg, or 3.6-5.9 kPa. The same author states that the softness and the way the body is supported are of fundamental importance from the point of view of ergonomics, which is directly related to the properties of the materials that make up the filling of the separate layers of the product. In upholstered furniture, polyurethane foams are often used to fill the elastic layer, which, depending on the frequency and conditions of use, wear out and deteriorate quite quickly. Wiaderek et al. (2016) write in their publication that the comfort of using furniture is influenced by factors such as: the construction of the seat, its shape and softness, the height of the usable surface, the type of furniture and the time of use. On the other hand, they define the term comfort as a state of subjective pleasure that results from the reaction to the environment. In the case of seats, a person in a sitting position affects the surface of the furniture (seat or backrest) with their mass, and the surface exerts pressure on the body. The feeling of discomfort is influenced by the pressure on the soft tissues of the human body. When the pressure in a person's blood vessels reaches 32 mmHg, pressure pain intensifies because these vessels close (Krutul 2004).

Grandjean (1978), in his work, describes comfort as a subjective term, because a person with a lower body mass will experience comfort differently than one whose body mass is higher. On the other hand, Dzięgielewski and Smardzewski (1995) believe that the term comfort of furniture use is also correlated with its functionality and is based on adaptation to the way of use, conditions and specific psychological and physical characteristics of a person. The functional dimensions of the furniture should be adapted to the anthropometric dimensions of the user to ensure safety and functionality (Hitka et al. 2023). The crucial objective indicator of seat comfort is the pressure distribution between the human–chair interface is recognized (Nicol et al. 1993, De Looze et al. 2003, Huang et al. 2015).

According to Matwiej (2011), "the comfort of using furniture products is directly related to their quality and can be determined based on measurements of:
- pressures generated on the contact surface of the user's body with the ground,
- contact surface of the user's body with the ground,
- deflection of upholstery layers."

The subject of comfort of using seating furniture was described by Grandjean (1978). He believes that the most important methods in the first half of the 1970s were the analysis of the behavior of sitting people and their physical sensations. At that time, the sitting position of people in train cars, in schools, and in lecture halls and offices was studied.

Wachsler and Learner (1960) used the following to determine the comfort of aircraft seats:
- the time a person can spend in a sitting position,
- the subjective feeling of comfort based on a survey,
- the time after which discomfort occurs.

Jones (1969) focused on the driver's comfort sensation when changing the position of his seat. The study also concerned the measurement of the changing body position during use and various settings of the driver's seat. Thanks to the research, he managed to obtain results for the optimal seat setting (seat height, seat depth, seat inclination, backrest angle), and results related to the subjective feeling when using the car seat.

Oshima (1970) conducted studies on the comfort of use depending on the dimensions of the chair. He created an experimental chair in which he changed the angle of the seat plane, the angle of the backrest, the height of the seat, and also changed the dimensions of its width. Then he created a questionnaire with points concerning the comfort of use (slipping of the buttocks forward, too narrow seat, uncertainty on the chair, fatigue, symptoms of pressure, feeling of pain, too hard seat) that had to be assessed by the people taking part in the study. The results and conclusions drawn from the tests allowed Oshima to construct accurate observations and theories for the future design of seating furniture.

Wiaderek et al. (2016) conducted research on the influence of the construction of selected seating furniture on the comfort of its use. Measurements were taken using a sensor mat, and a survey was conducted with volunteers participating in the study in order to learn about their subjective feelings about the comfort of selected upholstered seats. The research led to the conclusion that the use of different types of load-bearing layers affects the comfort of sitting and the quality of use.

The above considerations lead to the reflection that the comfort of using seating furniture is influenced by many factors. These include the materials used from which they are made, dimensions, ergonomic issues, the structure of the human body of users, as well as their subjective feelings. However, the subjective feeling is difficult to determine; even people of similar weight and height may experience comfort in a completely different way, so determining comfort on this basis does not provide clear results. Another important aspect is the issue of the gradual wear and tear of products, furniture that users use every day. In view of the above considerations, it was decided to carry out a study on the analysis of the comfort of using a selected piece of seating furniture before and after renovation.

Methods and materials

Selection of chairs for research

Two AGA chairs (Fig. 1) designed by Prof. Józef Chierowski were obtained for research. The date of this design is estimated at 1975, while the production itself is estimated at 1975-1977 (Anonymous 2022). AGA is a chair with a load-bearing construction consisting of a frame made of high-gloss varnished beech timber and an upholstered seat component.

The seat structure was based on the supporting subassembly of the supporting layer, consisting of an upholstery frame made of beech wood. In the upholstered part of this furniture, individual layers of the upholstery system were distinguished, i.e.:
- supporting layer, which was the carrier of utility loads, as well as other upholstery layers. According to Swaczyna, I. and Swaczyna M (1993), due to the impact of utility loads, this layer should be characterized by such features as flexibility, durability, strength, and elastic deformability. In the tested chairs, the structure of this layer was based on wave springs (covered with jute fabric),
- elastic layer (springless), which was made of polyurethane foams,
- covering layer, the task of which was to give the furniture an aesthetic appearance, but also to increase the durability of the entire upholstery. In upholstered chairs, the covering layer should be primarily resistant to pilling, abrasion, excessive dust accumulation, and the penetration of all types of dirt. It should also be characterized by high durability, elasticity, and color fastness (Swaczyna, Swaczyna 1993).

Before renovation, the chairs did not have a padding layer. The cover was stretched directly onto the foam.

Fig. 1. Chairs before renovation

General characteristics of selected chairs

Due to the very high visual similarity of both chairs tested, the designations "chair no. 1" were used for the chair visible on the left side of Figure 1 and "chair 2", which was shown on the right side. This division of names was made to facilitate the identification of chairs, both during the comfort of use tests and later renovation works.

General remarks

In order to examine the comfort of use of selected chairs, it was necessary to prepare a research station (Fig. 2), which consisted of the following elements: two AGA chairs, an FSA Clinical mat, Vista Medical, Ltd, the parameters of which are specified in Table 1, and a laptop. The person taking part in the study shown in Figure 2 belonged to the 50th percentile of the male population. According to Batogowska and Malinowski (1977), the 50th percentile of dimensions is defined as a measure that divides the population symmetrically into those users who have achieved a specific dimension and those who do not. The study did not take into account the subjective experiences of users, who found it difficult to clearly identify a piece of furniture with greater comfort.

First, pressure measurements were taken on the surfaces of the seat and backrest components of chair no. 1, and then on the same surfaces of chair no. 2. Measurements were taken once for each tested surface, and each measurement lasted about 60 seconds, taking into account only the time of exerting body pressure on the tested surfaces.

The values of contact stresses occurring during the loading of the tested chair surfaces with the user's body weight were recorded by the mFlex computer program. Direct results were exported via this software in the form of color stress distribution maps. The test results also included numerical values that allowed for calculating the contact stress distribution coefficient SPD and the discomfort coefficient D.

Fig. 2. Chair comfort testing station

Table 1. Parameters of the sensor mat used for research

Parameter name	Parameter value
Sensory surface	630 × 630 [mm]
Number of sensors	1024
Maximum measurable value	13,0 [kPa]

The contact stress distribution coefficient is determined based on the formula:

$$SPD = \frac{\sum_{i=1}^{n}(p_i - p_m)^2}{4np_m^2} \cdot 100[\%] \quad (1)$$

where:
SPD — contact stress distribution coefficient [%],
n — number of sensors in which contact stresses are different from zero [-],
pi — contact stress in any sensor of the mat [kPa],
pm — average contact stress for n sensors [kPa].

The discomfort factor D is determined based on the formula:

$$D = \frac{SPD \cdot p_m}{A}\left[\frac{daN}{m^4}\right] \quad (2)$$

where:
D — discomfort factor,
SPD — contact stress distribution coefficient [%],
pm — average contact stress [kPa],
A — contact area [m^2].

According to the same methodology, the comfort of using chairs was examined before and after the chairs were renovated.

The applied method represents an original research approach, being an innovative approach to the entire furniture renovation process for direct use, particularly for those pieces that include upholstered components. This method was developed at the Department of Furniture Design at the University of Life Sciences in Poznań and had previously been applied only once during the research described in the work by Szczyt (2020).

Selection of new upholstery systems used in chairs during renovation

Choosing the upholstery for chair no. 1

For chair no. 1, the original upholstery system was selected, both for the seat and backrest components, consistent with that which was in the chair before renovation. Additionally, a supplementary padding layer was used, which, according to Swaczyna and Swaczyna (1998), is used to create a surface that allows for the application of a covering fabric and to achieve "surface softness" of the furniture, rounded edges and evenness of the surface.

Materials used in chair no. 1 for:
- supporting layer — wave springs with a diameter of 3.8 mm, length of 480 mm, and a wave pitch of 5 cm, covered with jute fabric,
- elastic layer (springless) — a 4 cm thick polyurethane foam T3042 form,
- padding layer — 100 g/m^2 cotton wool,
- covering layer — ITAKA 65 fabric.

Choosing the upholstery for chair no. 2

For chair no. 2, an upholstery system was selected using a rigid supporting layer for the seat subassembly and an elastic layer for the backrest subassembly. The change in the structure of the upholstery layers in chair no. 2 was made in order to compare the comfort of use of two identical chairs with different upholstery materials used inside the systems.

Materials used in the seat of chair no. 2 for:
- supporting layer — 6 mm thick plywood,
- elastic layer — 2 cm thick polyurethane foam T4050 and 2 cm thick polyurethane foam T2520,
- padding layer — 100 g/m^2 cotton wool,
- covering layer — ITAKA 65 fabric.

Covering fabric characteristics:
- weight: 230 g/m^2,
- composition: 100% PES (polyester),
- fabric intended use: inside buildings, in rooms not exposed to direct UV radiation and other weather conditions, such as rain, snow, low and high temperatures,
- abrasion resistance: 100,000 cycles according to the Martindale test: the Martindale test is an indicator to consider when choosing upholstery fabric. It determines its abrasion resistance, which is crucial for seating furniture. The test result characterizes the fabric's durability and possible applications. Below are the values (number of cycles performed) and the characteristics of the Martindale test:

  - 10,000-15,000: for light home use,
  - 15,000-25,000: for everyday home use,
  - 25,000-30,000: for intensive home use (e.g., for corners where we also use the sleeping function),
  - 30,000-40,000: for office use,
  - >40,000: for intensive commercial and public use (e.g., for coach seats),
- piling: 5 – the pilling phenomenon manifests itself as the formation of small balls and knots on fabrics (Korzeniewska et al. 2019). The tendency of materials to pilling and pilling is determined according to the PN-EN ISO 12945-2:2021-04 standard — Determination of the tendency of a flat product surface to pilling, pilling and balling. A five-point scale is used to determine pilling. The highest level (5) means that the material is 100% resistant to this type of damage, even long-term and intensive use does not cause pilling or pilling of the fabric.
- type: plush,
- features: waterproof fabric.

Results and discussion

The main objective of this study was to compare the comfort of two AGA chairs before and after renovation. This objective was achieved by examining the comfort of the seat and backrest of both chairs using a sensory mat. The results and their discussion are presented below.

The results of the research conducted

Figures 3 to 6 present pressure distribution maps, which are a direct result of the user comfort tests.

The results of the SPD and D coefficient for chairs no. 1 and 2 before and after renovation are presented in tables 2-5.

Analysis of research results

The values of the contact distribution coefficient SPD for the seat of chair no. 1 before and after renovation are presented in Table 2. They were 24.2% before renovation and 15.61% after renovation, respectively. Thus, a decrease in the SPD coefficient value of 8.59% was noted. A decrease in the SPD coefficient value from 21.44% to 11.21% was also noted for the backrest of chair no. 1.

Analyzing the formula based on which the SPD coefficient was calculated, it can be stated that it should be equal to zero when the contact stress distribution on the seat surface is more uniform, and the stress pi in any sensor should be equal to the mean stress pm.

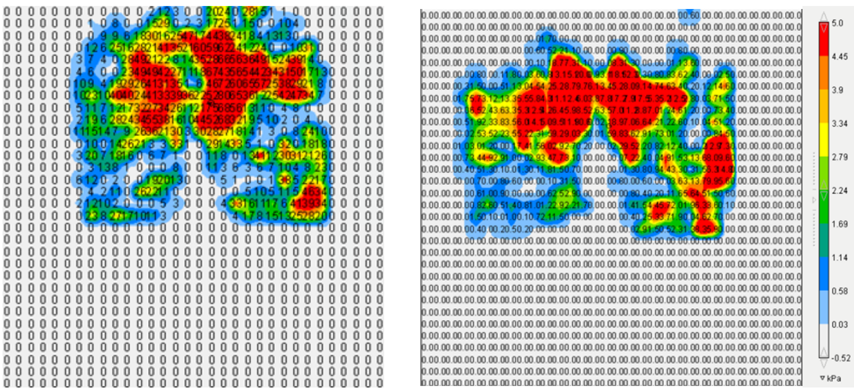

Fig. 3. Pressure distribution maps on the seat of chair no. 1 in a sitting position supported: a – before renovation, b – after renovation

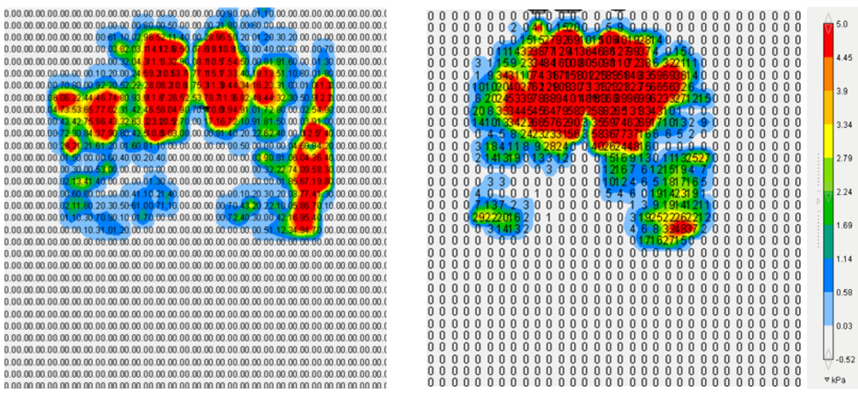

Fig. 4. Pressure distribution maps on the seat in the sitting position leaning before (a) and after renovation (b) for chair no. 2

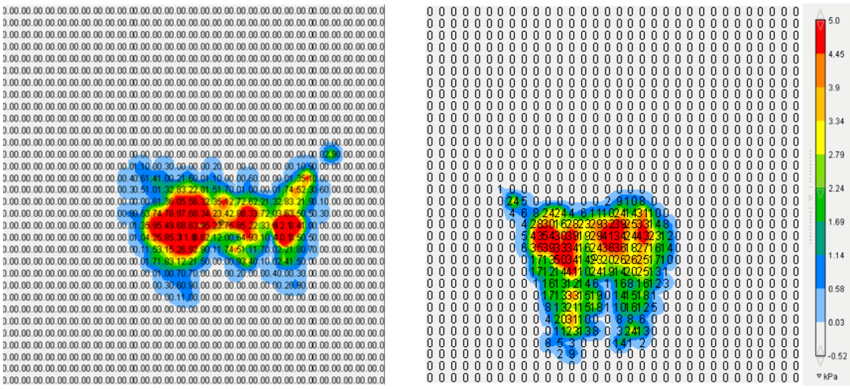

Fig. 5. Pressure distribution maps on the backrest in the sitting position before (a) and after renovation (b) for chair no. 1

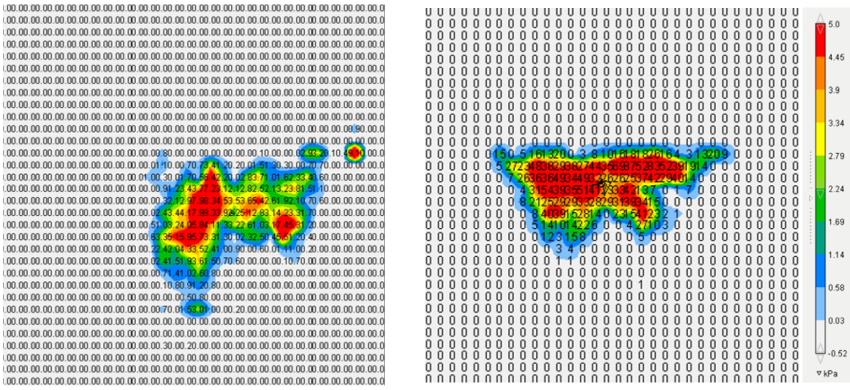

Fig. 6. Pressure distribution maps on the backrest in the sitting position before (a) and after renovation (b) for chair no. 2

Table 2. Summary of SPD coefficient results for chair no. 1 before and after renovation

Position	Subassembly	SPD [%]	
		Before renovation	After renovation
sitting, leaning back	chair seat	24,2	15,61
	chair backrest	21,44	11,21

Table 3. Summary of SPD coefficient results for chair no. 2 before and after renovation

Position	Subassembly	SPD [%]	
		Before renovation	After renovation
sitting, leaning back	chair seat	28,34	28,41
	chair backrest	19,73	13,93

Table 4. Summary of the D coefficient results for chair no. 1 before and after renovation

Position	Subassembly	D	
		Before renovation	After renovation
sitting, leaning back	chair seat	12,04	5,61
	chair backrest	16,68	6,88

Table 5. Summary of the D coefficient results for chair no. 2 before and after renovation

Position	Subassembly	D	
		Before renovation	**After renovation**
sitting, leaning back	chair seat	13,55	19,27
	chair backrest	11,23	14,01

Therefore, seats with low SPD values may indicate more uniform support of the user's body than those with high values. The reduction in the SPD coefficient value in chair no. 1 after renovation indicates that the body support by the seat, but also by the backrest, is more uniform than before renovation, which is also shown by the stress distribution maps in Figures 3 and 5. After a short visual analysis of these figures, it is noticeable that on both the seat and backrest, after renovation, the area of the surface on which stress was recorded is larger.

A different situation was observed in the case of the results obtained for chair no. 2 and presented in Table 3. The contact stress distribution coefficient SPD turned out to be 0.07% higher after the renovation for the seat, while 5.8% lower for the backrest. The changes in stresses of the tested surfaces are presented in Figures 16 and 18, respectively. The pressure maps created after the renovation of chair no. 2 showed an increase in the red area, which, according to the scale, presents values equal to or greater than 4.45 kPa (32 mmHg). This situation indicates a deterioration in the comfort of use of the tested surfaces, because the value of 4.45 kPa is the limit value at which the lumen of blood vessels in humans is closed.

This situation was influenced by the use of different upholstery materials than in chair no. 1. They caused the SPD values for the seat to be higher, but very similar to those tested before renovation. The backrest of chair no. 2, also differing in upholstery layers from chair no. 1, made of elastic upholstery belts and two types of foam (such as those used in the seat), showed lower pressure values after renovation, but higher SPD values, compared to the backrest of chair no. 1 after renovation.

It is also worth noting that the structures of both chairs were made in the same way before renovation, and the results of the SPD and D coefficients were not very similar. This situation indicates that the chairs had different degrees of wear on the upholstery layers before renovation.

As far as the analysis of the D coefficient is concerned, it would be expected that high stresses pm, high values of the SPD coefficient, as well as low A values, will contribute to high discomfort when using the seat. When the discomfort factor reaches low values, it indicates that the seat comfort is high.

Analyzing the values of the D coefficient shown in Table 4, obtained as a result of the tests of chair no. 1, it was observed that the comfort of using the chair improved after renovation. Before renovation, the value of this coefficient for the seat was 12.04 $\left[\frac{daN}{m^4}\right]$ and after renovation 5,61 $\left[\frac{daN}{m^4}\right]$. Therefore, there was a decrease of 6.43 $\left[\frac{daN}{m^4}\right]$. A similar situation occurred in the case of the results for the backrest of chair no. 1. The discomfort coefficient D decreased from 16.68 $\left[\frac{daN}{m^4}\right]$ before renovation, to the value of 6.88 $\left[\frac{daN}{m^4}\right]$ after renovation.

In the case of chair no. 2, the obtained discomfort coefficient D, the values of which are presented in Table 5, increased for the tested seat and backrest.

Fig. 7. The chair model intended for outdoor use, studied by Łykowska (2017)

For the seat, an increase of 5.72 $\left[\frac{daN}{m^4}\right]$ was noted, while for the backrest by 2,78 $\left[\frac{daN}{m^4}\right]$.

The obtained results can be related to other similar studies of furniture seat components intended for sitting, conducted by authors analyzing pressures on the human body using a sensor mat. Łykowska (2017) undertook an analysis of the contact pressure values generated on the user's body by eight chairs, the model of which is presented in Figure 7.

During the analyses, the author obtained results in the form of the discomfort coefficient D and the SPD coefficient, the values of which are presented in Table 6.

Analyzing the values of the coefficients presented in Table 6, it should be noted that the chairs subjected to renovation demonstrate significantly better ergonomic performance in terms of user comfort, which may indicate that the seat construction and materials used for the renovation were appropriately selected. Similarly, based on the research results of Sala (2021) and the obtained values of the discomfort coefficient D in various configurations of foam layer arrangements (Table 7), it can be concluded that the conducted renovation, particularly of chair no. 1, yielded very positive outcomes regarding comfort and ergonomic use.

Conclusions

Two AGA upholstered chairs were renovated. Chair no. 1 was made using the reconstructive method, which means that the upholstery layers were made in the same way as in the original chair before renovation. In chair no. 2, however, the materials in the upholstery systems were changed. It should be emphasized that the wear of the examined chairs was already somewhat varied before the renovation, which naturally resulted from the intensity and manner of their use.

Table 6. Summary of the SPD and D coefficient values

Chair	SPD [%]	D [N/m^4]
1	62,21	34,53
2	60,40	32,61
3	60,77	34,13
4	61,07	28,78
5	63,61	36,82
6	60,79	35,39
7	65,48	31,59
8	63,05	33,15

Table 7. Catalog of user comfort dependencies for a seat system with 60 mm foam thickness

System			D
Top layer	Middle layer	Bottom layer	
T-25	T-21	HR-3537	7,70
T-21	T-25	HR-3537	8,30
HR-3537	T-21	T-25	9,03
T-25	HR-3537	T-21	9,21
HR-3537	T-25	T-21	9,66
T-21	HR-3537	T-25	9,67
T-25	HR-3537	XPE	15,14
HR-3537	T-25	XPE	17,31
T-21	T-25	XPE	21,62
T-25	T-21	XPE	23,64
T-21	HR-3537	XPE	24,39
HR-3537	T-21	XPE	24,84

Both before and after renovation, the chairs were tested to obtain color maps of pressure distributions, determine the contact stress coefficient SPD, and the discomfort coefficient D. As a result of the analysis of the results of these tests, it was found that:

– for chair no. 1 – the values of the contact stress distribution coefficient SPD and the discomfort coefficient D were lower than the test results for the chair before renovation, which indicates an improvement in the comfort of use of the given chair.
– for chair no. 2 – the values of the contact stress distribution coefficient SPD and the discomfort coefficient D were higher than the test results for the chair before renovation, which indicates a deterioration in the comfort of use of the given chair.

It follows that during the renovation of worn-out chairs, the restoration of their original structure results in the restoration of previous functional properties. However, changes to the structure/construction of the upholstery system introduced during renovation may fail to restore the initial level of comfort.

As research has shown, by determining the values of the contact stress distribution coefficient (SPD) and the discomfort coefficient (D), it is possible to objectively assess the comfort of furniture. This research could certainly contribute to the wider use of this method, allowing for comparisons with other chairs, including those undergoing renovation.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

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