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TECHNOLOGICAL GOODNESS INDEX FOR FURNITURE DESIGN

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ABSTRACT

Managing an ever-growing number of components is technologically challenging for furniture manufacturers; therefore, minimizing produced components' "dimensional entropy" is necessary. A novel method to assess how dimensional decisions made during furniture design influence the growth of the components' dimensional entropy is proposed in the article. The dimensions of each newly designed element were compared to a specific set of preferred dimensions. This approach facilitates furniture design using dimensionally unified components. The Jaccard coefficient for fuzzy sets was employed to achieve it. The obtained similarity score was called the "technological goodness index" (TGI) of furniture.This index can be calculated at three levels: for a group of furniture items, a single piece, and the furniture components. Using the TGI in the CAD, manufacturers gain insight into their newly designed products' "technological" quality. By analyzing this data, designers can create furniture that boosts production efficiency, promotes productivity, and cost savings.

Keywords: technological quality assessment; standardization; dimensional optimization; technological indexes in the furniture industry; Product Data Management system.

INTRODUCTION

Furniture manufacturers tackle the market challenges by offering many sizes for optimal functionality and spatial room fit. Designers consider trends in design, new materials, scientific discoveries in ergonomics and production technology, and (most importantly) customers' requirements expecting unique, non-series furniture (Suandi *et al.*, 2022; Hitka *et al.,* 2024). The constant development of technology creates the need to expand existing research activities to optimize the production structure (Grzegorzewska *et al*., 2020). Computerization in design and production has increased the variety of furniture dimensions available, with shorter production runs for each variation. A typical furniture factory has documented millions or even tens of millions of furniture components from which finished products are made (Gómez *et al.*, 2021).

People have been standardizing the dimensions of artifacts for a long time, as exemplified by ancient and modern canons of the human body and numerous attempts to determine ideal proportions in architecture, sculpture, and painting (Jasińska *et al*., 2024). Industrial product standardization also comes in many forms (Lu *et al.,* 2020), such as the preferred sizes in a series of products. In 1952, the International Electrotechnical Commission introduced the Renard series through Recommendation R3 (IEC) to standardize the ratings of electrical voltages and currents (ISO 3 1973). A similar recommendation also applies to the preferred metric dimensions of products and their components (ISO 17 1973, ISO 497).

Preferred metric product sizes are described by international standards that simplify the use of the metric system in engineering. Examples of standards include the 1-2-5 series, arithmetic sequence, convenient numbers, and many others used in technology (Milton, 1978). In gastronomy, Gastronorm is used (PN-EN 631 1996) in industry Euro container (VDA 4500 standard) and Euro-pallet (set of standards, e.g., (ISO 445 2013) (Rubert *et al.*, 2023). Other standards define the size of preferred metric parts, for example, machine screw sizes, pulley sizes, ventilation pipe diameters, etc.; all are based on Renard's series. The furniture industry uses a non-standardized "system 32" and the standardized basic size module (ISO 2848 1984) for cabinet furniture. All these systems have two beneficial features: they reduce the variety of product dimensions and cause other items to cooperate with standardized products with a reduced variety of sizes.

The problem of material storage costs and production complexity is greater when the production runs are shorter. With large-scale production and frequent changes in produced collections, the issue of the multiplicity of diverse elements is significant. Considering this, reducing the dimensional diversity of products offers several benefits: lower inventory costs, smooth production processes, leverage economies of scale in material ordering, enhanced quality control, improved lead times, and enhanced productivity. However, there are also potential drawbacks to consider. Offering fewer size options might limit the manufacturer's ability to cater to a broader range of customer needs. Standardization can lead to a more homogeneous market, where competition focuses on price rather than unique features. Therefore, it seems that the optimal solution is the dimensional diversification of products, but involving the introduction of dimensionally ordered products.

A limited set of cardinal dimensions can be defined for furniture elements, ensuring consistency with established sizing systems. These systems may include arithmetic sequences, the Renard series, sequences of preferred numbers, the Fibonacci sequence, or any system outlined in technical standards or relevant to the specific technology field. Designing new furniture elements consistently with a chosen "cardinal dimensions" system minimizes the variety of component sizes (dimensional entropy). This, in turn, simplifies production planning. In this approach, a "technologically good" piece of furniture is designed consistently according to a selected design rule. Regardless of the chosen "cardinal dimensions" system, the degree of consistency of its application is essential. "Technological goodness" should be understood as the degree of integrity of a particular piece of furniture or family. The work aims to propose how to define the set of cardinal dimensions of a furniture element and to propose an analytical method for comparing the similarity of this set to the newly designed furniture.

MATERIALS AND METHODS

Interviews conducted with wood technologists and furniture designers show that companies have a problem with too many furniture collections, varieties of furniture piece variants, and produced furniture components. Based on this, it is stated that "technological goodness" can be determined at three levels: a group of furniture items, a single piece, and the furniture components. As a result, the indicator is tripartite, as shown in Figure 1.

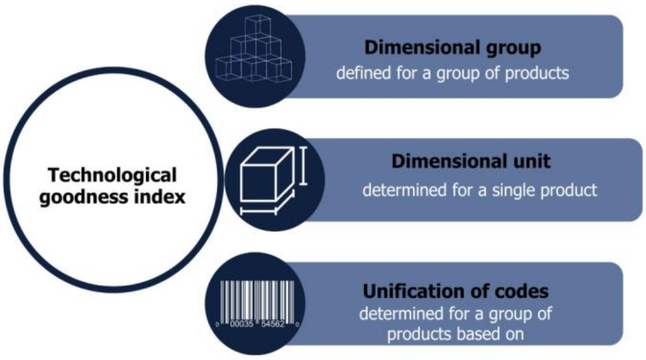

Fig. 1 Triple division of the technological goodness index (own work).

Industrial enterprise resource planning software (ERP) assigns unique identifiers (part numbers, or codes) to each component. In this approach, "technological goodness" is understood as striving for the maximum reduction of newly created codes during new furniture design.

Evaluating a furniture item's technological efficiency involves a four-step process: preparing a list of the cardinal dimensions, selecting the principle of dimensional unification, applying an appropriate mathematical method, and comparing the values of the cardinal dimensions of the furniture with the desired values (Fig. 2).

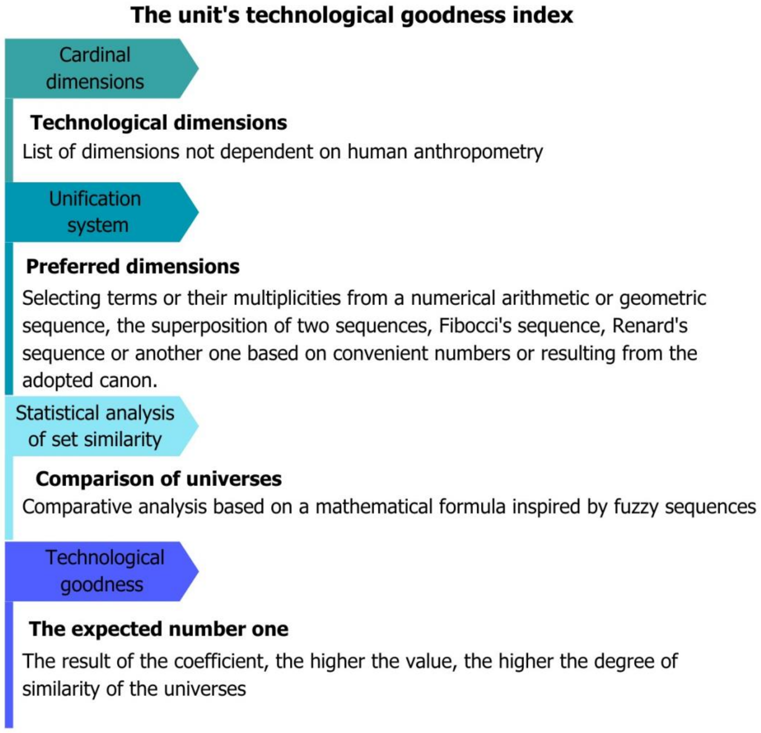

Fig. 2 Scheme for assessing the technological goodness index of a furniture item (own work).

The first step in the path presented is the selection of cardinal dimensions of the piece of furniture. Cardinal dimensions subject to evaluation, and those not subject to evaluation can be distinguished when determining the technological goodness index. This comparison is depicted in Figure 3.

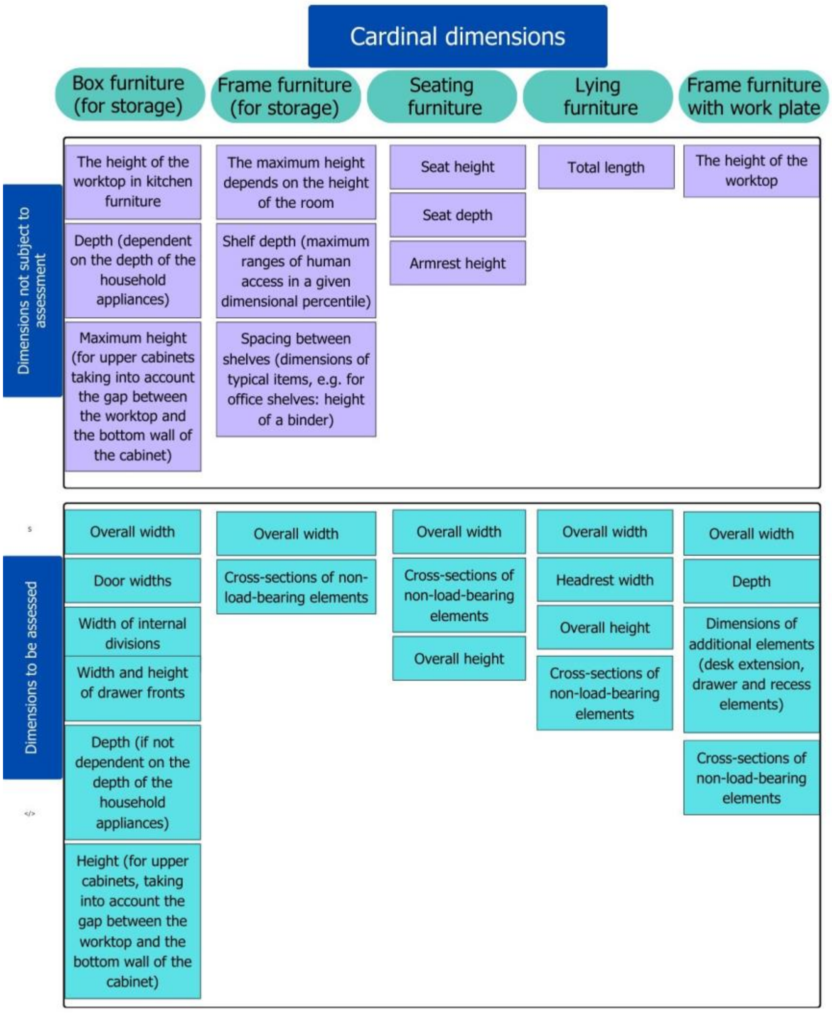

Fig. 3 Proposal for dividing cardinal dimensions into those not subject to assessment and those subject to evaluation depending on the group of furniture (own work).

In the classical sense, cardinal dimensions fundamentally impact the furniture's functionality and comfort; therefore, they are concerned with the position and dimensions of the user's body when using the furniture. These include, for example, the height and depth of the seat and the height of the backrest or armrests (in the case of chairs, sofas, armchairs, and other seating furniture), the height of the countertop (in tables, desks, kitchen countertops and other furniture with a work surface), the height of the shelves and drawers (in the case of shelves, wardrobes, hanging and standing cabinets, chests of drawers), overall dimensions (width, height, and depth) in the context of the furniture's location in space. The indicated dimensions are somewhat standardized, and knowledge about them is also widely available to furniture customers, i.e., nonspecialist designers (Tilley and Dreyfuss 2001). Reliable information about them can be found, for example, in anthropometric atlases showing the measurements of the human body and its ranges. The selection of these dimensions should not be assessed due to the adopted ergonomic schemes. Dimensions that are more difficult to choose are those not determined by laws consistent with human anatomy. Such dimensions include, for example, the width of furniture doors, internal divisions, and, therefore, the location of partition walls (in box and frame furniture), the width of the worktop, width, and depth (especially in box furniture), and the thickness of the sections of elements that are not load-bearing elements.

After completing a series of technologically preferred cardinal dimensions suitable for the technology of the assessed piece of furniture, the next step is to state the set of cardinal dimensions of the analyzed piece of furniture. The similarity of the series of technologically preferred cardinal dimensions can be compared with the set of preferred dimensions. This allows for determining the "technological goodness index of the furniture".

There are many methods for comparing the similarity of two data sets and the choice of the appropriate one depends on the specificity of the data whose similarity needs to be compared and the purpose of this analysis. Each method has its uses and limitations. Commonly used methods for assessing the similarity of sets are the Jaccard Index (Costa, 2021), Hamming Distance (Norouzi *et al.*, 2012), Levenshtein Distance (Behara *et al.*, 2020), Dice Index (Ye & Ye 2014), Tanimoto Index (Bajusz *et al.*, 2015), Mahalanobis distance (Durak, 2011), Russell and Rao coefficient (Boyce & Ellison, 2001) and Cosine Similarity Index (Ye, 2011). The entropy of sets is also determined as a measure of diversity, the determination of which is preceded by the segmentation of the set into groups or regions (Jakulin & Bratko, 2004). The Jaccard index is widely used in various types of problems. Its modifications have been created, allowing, for example, to consider the level of relative internality between two compared entities, adding multiple sets, densities, and general scalar fields, and determining the joint interdependence between two random variables (Costa, 2021).

Two sets (classified into fuzzy sets) can be compared based on the Jaccard coefficient. Based on this, an analysis can compare the universe of selected dimensions of the analyzed furniture and the universe of preferred dimensions.

A fuzzy set A in the universe X is defined using the equation: $A = \{(x, \mu(x)) : x \in X,\ \mu_A(x) \in [0;1]\}$, where $\mu_A(x): X \to [0;1]$ is the membership function of the fuzzy set A, representing the degree of membership of elements in the set X to the fuzzy set A (Zadeh 1965). The essence of the fuzzy set concept is to determine the degree of belonging of elements to it. Each element $x \in X$ can fully belong to the fuzzy set A, not belong to it at all, or belong to it to a certain degree. Accurately assigning degrees of membership to objects in the universe $x \in X$ is often challenging. This operation is typically subjective and context-dependent. The evaluation of the degree of membership of an element in the universe $x \in X$ to the fuzzy set A depends on the membership function.

Two fuzzy sets A and B defined on a specific universe X are identical if and only if each element of this universe belongs to both sets A and B to the same extent (Łachwa 2008). The similarity between two distinct sets, like A and B, can be quantified using a similarity measure. This measure assigns a value between 0 and 1, with 0 indicating no overlap and 1 indicating identical sets. These values describe the degree of similarity, ranging from identity (complete similarity): 1 to complete dissimilarity: 0.

The most commonly used measure of similarity is the Jaccard coefficient. Its extension to fuzzy sets is given by (Lin & Lee, 1992):

$$s_{A,B} = \frac{g(A \cap B)}{g(A \cup B)}, \qquad g(A \cup B) \neq 0, \tag{1}$$

Where: g is any function satisfying the conditions:

1) $g(\emptyset) = 0$,
2) $g(X) = 1$,
3) if $A \subset B$, then $g(A) \leq g(B)$,

where $\emptyset$ – represents the empty set, X – universe.

RESULTS AND DISCUSSION

Two fuzzy sets (A and B) are created to determine a unit's technological goodness index. The sets were created to analyze a kitchen cabinet Polimeb (Fig. 4).

Fig. 4 The analyzed Polimeb kitchen furniture "Furniture with adjustable widths and a variable number of sections", patent application PL439195A1 (own work).

The calculations were performed using a spreadsheet editor (Microsoft Excel, Redmond, WA, USA). The charts were created using R (version 4.3.0*, R Core Team 2023) with the R ggplot2 package (version 3.4.2).

It was assumed that fuzzy sets A and B are of the form:

$A = \{(x, \mu_A(x)): x \in X,\ \mu_A(x) \in [0; 1]\}$,

$B = \{(x, \mu_B(x)): x \in X,\ \mu_B(x) \in [0; 1]\}$,

Where: X represents the universe, a set of natural numbers from 1 to 143,

$\mu_k(x)$ – represents the degree of membership of elements $x \in X$ in fuzzy set k, Where: $k \in \{A, B\}$.

For any fuzzy set A, a membership function is proposed $\mu_A(x) = f(w^A)$,

Where: w^A - represents the cardinal dimensions of the analyzed Polimeb piece of furniture (listed in Table 2),

$f(w)$ – a function described by the formula:

$$f(w) = \begin{cases} 1 & \text{for } |w - an| < \Delta w \\ \dfrac{-1}{50 - 2\Delta w}(w - an - \Delta w) + 1 & \text{for } an + \Delta w \le w \le an + 50 - \Delta w \\ \dfrac{1}{50 - 2\Delta w}(w - an + 50 - \Delta w) & \text{for } an - 50 + \Delta w \le w \le an - \Delta w \\ 0 & \text{for } |w - (an + 50)| < \Delta w \end{cases}, \quad (2)$$

Where: $a \in R_+$ – the smallest standard dimension, any positive real number,

$n \epsilon N_+$, where an denotes the multiple of the standard dimension,

Δw – specifies the acceptable deviation of a dimension from the standard dimension.

For any fuzzy set B, a membership function is proposed $\mu_B(x) = f(w^B)$, where

w^B – the dimensions recognized as a standard. It can be observed that $\mu_B(x) = 1$ for every $x \in X$. Thus, the equality holds: $B = \{(x, 1): x \in X, \}$

The graph of the function $f(w)$ described by formula (1) is presented in Figure 5.

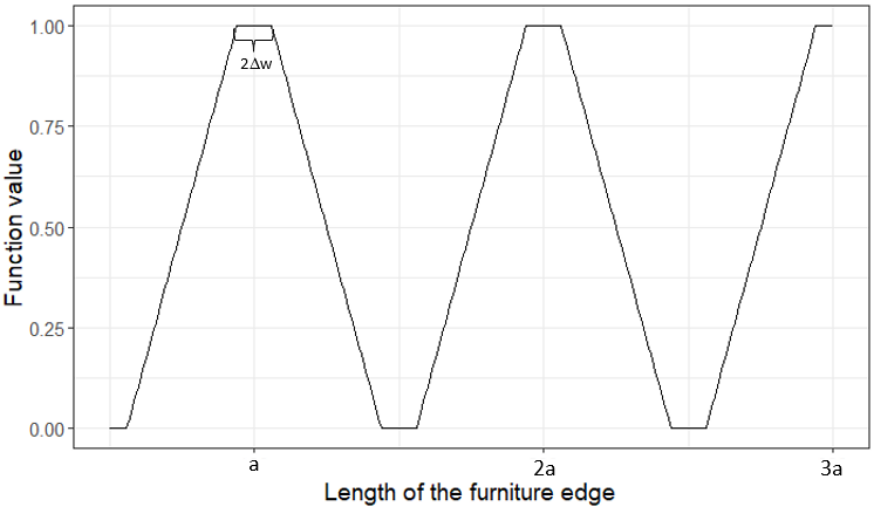

Fig. 5 The graph of the function $f(w)$ described by formula (1).

Assuming that the standard dimensions are multiples of the number 100 ($a = 100$), the function $f(w)$ takes the form:

$$f(w) = \begin{cases} 1 & \text{for } |w - 100n| < \Delta w \\ \frac{-1}{50-2\Delta w}(w - 100n - \Delta w) + 1 & \text{for } 100n + \Delta w \le w \le 100n + 50 - \Delta w \\ \frac{1}{50-2\Delta w}(w - 100n + 50 - \Delta w) & \text{for } 100n - 50 + \Delta w \le w \le 100n - \Delta w \\ 0 & \text{for } |w - (100n + 50)| < \Delta w \end{cases} \quad (3)$$

Additionally, if $\Delta w = 0$ mm. the form of the function $f(w)$ is as follows:

$$f(w) = \begin{cases} \frac{-1}{50}(w - 100n) + 1 & \text{for } 100n \le w < 100n + 50 \\ \frac{1}{50}(w - 100n + 50) & \text{for } 100n - 50 \le w < 100n \end{cases}; \quad (4)$$

if $\Delta w = 1$ mm, function $f(w)$ takes the form:

$$f(w) = \begin{cases} 1 & \text{for } |w - 100n| < 1 \\ \frac{-1}{48}(w - 100n - 1) + 1 & \text{for } 100n + 1 \le w \le 100n + 49 \\ \frac{1}{48}(w - 100n + 49) & \text{for } 100n - 49 \le w \le 100n - 1 \\ 0 & \text{for } |w - (100n + 50)| < 1 \end{cases}; \quad (5)$$

if $\Delta w = 10$ mm, function $f(w)$ is as follows:

$$f(w) = \begin{cases} 1 & \text{for } |w - 100n| < 10 \\ \frac{-1}{30}(w - 100n - 10) + 1 & \text{for } 100n + 10 \le w \le 100n + 40 \\ \frac{1}{30}(w - 100n + 40) & \text{for } 100n - 40 \le w \le 100n - 10 \\ 0 & \text{for } |w - (100n + 50)| < 10 \end{cases}. \quad (6)$$

Figure 6 shows the graphs of the functions f described by formulas (3), (4), (5) and (6).

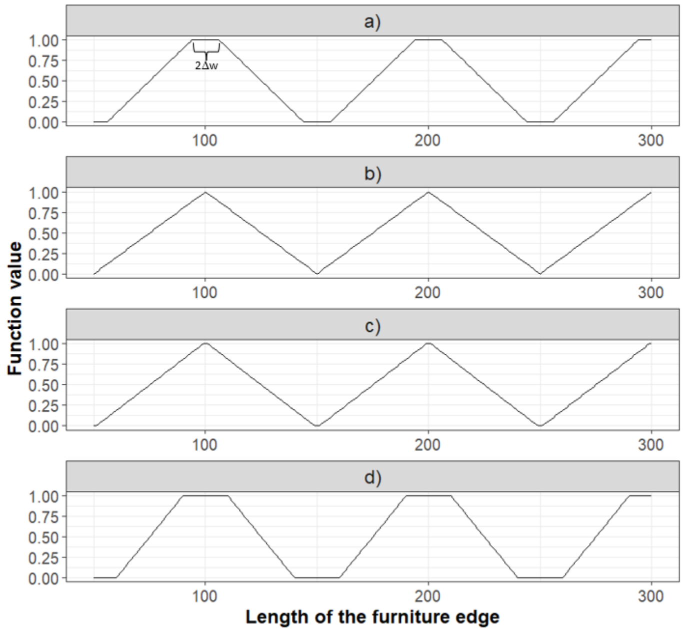

Fig. 6 Plots of the functions f described by formulas (3), (4), (5), and (6), assuming that the standard dimensions are multiples of the number 100 and that the acceptable dimension deviation from the standard dimension is respectively at levels: a) Δw, b) $\Delta w = 0$ mm, c) $\Delta w = 1$ mm, d) $\Delta w = 10$ mm.

The similarity measure was determined based on the extended Jaccard coefficient for fuzzy sets.

It was assumed that the function g takes the form:

$$g(A) = \frac{\sum_{i=1}^{n} \mu_A(x_i)}{|X|} \text{ for } x_i \in X, \tag{7}$$

Where: $|X|$ – denotes the cardinality of the universe.

It can be noticed that the function in the form of (7) satisfies all the conditions required for any function g contained in formula (1).

The calculated similarity measure values for the considered sets A and B, depending on the acceptable deviation of a dimension from the standard dimension, are presented in Tab. 1.

Tab. 1 Similarity measure values for the considered sets A and B, depending on the acceptable deviation of a dimension from the standard dimension.

	$\Delta w = 0$ mm	$\Delta w = 1$ mm	$\Delta w = 10$ mm
$s_{A,B}$	0.100685	0.100724	0.204495

Based on the results of the similarity measure, it can be seen that for the analyzed Polimeb furniture, with the increase in the acceptable deviation of the dimension from the standard dimension, the similarity of fuzzy sets A and B increases.

Assuming that the dimensions of the furniture under consideration are in the range $[100n - 25, 100n + 25]$, meaning it is ± 25 of the standard dimension, the values of the function $f(w)$ and the values of the membership function $\mu_A(x)$ increase with the increasing value of the acceptable dimension deviation from the standard dimension Δw.

On the other hand, when the dimension of the analyzed furniture falls within the range $[100n + 25, 100(n + 1) - 25]$, meaning it is more than 25 away from the standard dimension, the values of the function $f(w)$ and the values of the membership function $\mu_A(x)$ decrease with the increase in the value of the acceptable deviation of the dimension from the reference dimension Δw (Tab. 2).

Tab. 2 Cardinal dimensions of the analyzed Polimeb piece of furniture (w^A), standard dimensions (w^B) and results obtained by applying functions f described by formulas (4), (5), and (6).

$x = i, i \in \mathbb{N}_+$	w^A	$\mu_A(x)$			w^B	$\mu_B(x)$
		$\Delta w = 0$	$\Delta w = 1$	$\Delta w = 10$		
$i\epsilon\{1,2,\ldots,16\}$	128	0.44	0.44	0.4	100	1
$i\epsilon\{17,18,19,20\}$	151	0.02	0	0	200	1
$i\epsilon\{21,22,\ldots,28\}$	300	1	1	1	300	1
$i\epsilon\{29,30,31,32\}$	428	0.44	0.44	0.4	400	1
$i\epsilon\{33,34,\ldots,50\}$	432	0.36	0.35	0.27	400	1
$i\epsilon\{51,52\}$	448	0.04	0.02	0	400	1
$i\epsilon\{53,54,\ldots,60\}$	450	0	0	0	400	1
$i\epsilon\{61,62\}$	478	0.56	0.56	0.6	500	1
$i\epsilon\{63,64\}$	480	0.6	0.6	0.67	500	1
$i\epsilon\{65,66,67,68\}$	500	1	1	1	500	1
$i\epsilon\{69\}$	502	0.96	0.98	1	500	1
$i\epsilon\{70,71,72,73\}$	591	0.82	0.83	1	600	1
$i\epsilon\{74,75,\ldots,81\}$	600	1	1	1	600	1
$i\epsilon\{82,83\}$	736	0.28	0.27	0.13	700	1
$i\epsilon\{84,85\}$	770	0.4	0.4	0.33	800	1
$i\epsilon\{86,87,\ldots,93\}$	784	0.68	0.69	0.8	800	1
$i\epsilon\{94,95,\ldots,101\}$	803	0.94	0.96	1	800	1
$i\epsilon\{102,103,104,105\}$	810	0.8	0.81	1	800	1
$i\epsilon\{106,107,\ldots,123\}$	824	0.52	0.52	0.53	800	1
$i\epsilon\{124,125\}$	916	0.68	0.69	0.8	900	1
$i\epsilon\{126,127,128,129\}$	1222	0.56	0.56	0.6	1200	1
$i\epsilon\{130,131\}$	1444	0.12	0.1	0	1400	1
$i\epsilon\{132,133\}$	1928	0.44	0.44	0.4	1900	1
$i\epsilon\{134,135,136,137\}$	1946	0.08	0.06	0	1900	1
$i\epsilon\{138,139\}$	1962	0.24	0.23	0.07	2000	1
$i\epsilon\{140,141\}$	1969	0.38	0.38	0.3	2000	1
$i\epsilon\{142,143\}$	2262	0.24	0.23	0.07	2300	1

The technological goodness index for a group of products can be determined similarly to the individual one, with the appropriate designation of universes. It is suggested that dimensions from set A, which show low similarity to dimensions from set B, should be corrected at the early stages of the design process. The acceptable minimum degree of similarity can be determined individually, and the number of designed dimensions below the acceptable level relative to all evaluated dimensions indicates the degree of integration with preferred dimensions.

Determining the third type of technological goodness index supports assessing the functionality of created databases and production management systems. For the database to be helpful, it is crucial to establish uniform data standards, specifying the appearance of product codes, units of measurement, and data formats. The developed database is integrated with the existing Enterprise Resource Planning (ERP) internal system. This ensures a smooth exchange of information between various sectors of the company. Additionally, it has to specify who has access to particular parts of the database and how changes are made. The critical steps in creating a central database in the furniture industry are shown in Figure 7.

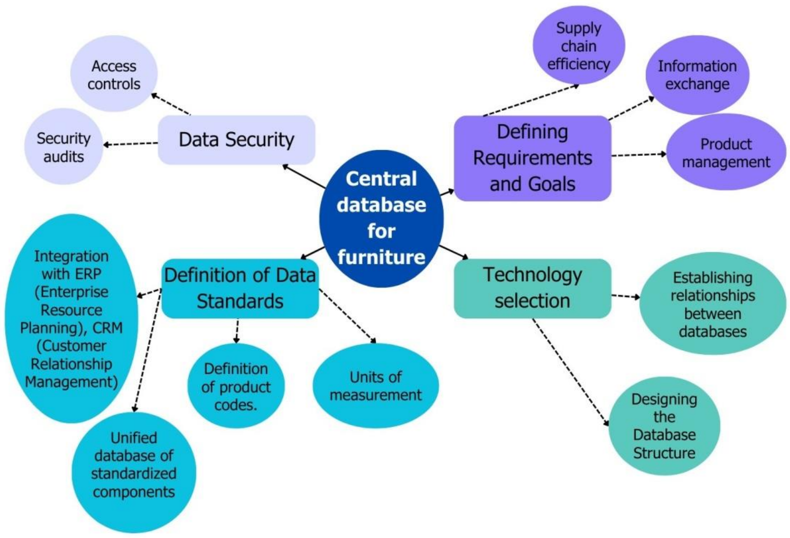

Fig. 7 Steps in creating a central furniture database (own work).

Each technological operation, component, and finished product receives an alphanumeric code. They are created according to a pattern but not necessarily unified. The unification aims to facilitate identifying, managing, and exchanging information about furniture products between various entities, such as manufacturers, suppliers, furniture stores, and e-commerce platforms. Unified codes in the context of data management systems such as databases provide easier identification and tracking. These tools facilitate quick record location, making them invaluable for large datasets. Unified codes facilitate interoperability and information exchange between different platforms or applications in cases where data is shared across various systems. Conflicts and redundancies are avoided with unified, non-duplicate codes. Ensuring the consistency and transparency of the system, in turn, affects the quality of data. The search time is reduced, which speeds up access to the necessary information.

Figure 8 on the left shows an illustrative design made in Top Solid, using libraries of connectors and components; on the right is the same piece of furniture with assigned color attributes of individual elements following the recommended methodology. The final color versions are combined under one code as a variant. When importing a file from Top Solid, an app window allows users to review the codes selected by the system, identify those to be created as new ones, and understand how the design considers color configuration characteristics and their subsequent propagation. Users can reconsider the import, correct the design in Top Solid, and start the import process again.

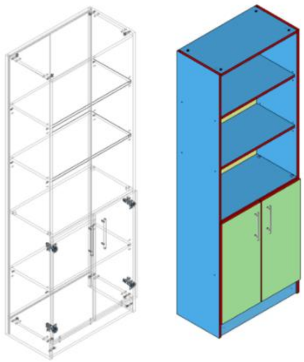

Fig. 8 Illustrative design made in Top Solid, using libraries of connectors and components and a view of the furniture with assigned color attributes of individual elements (Fide materials).

The technological goodness index for codes (I_c) can be determined by calculating the ratio of the number of newly created codes (c) to the total number of codes presented in the product list (C):

$$I_c = \frac{c}{C}$$

where: c– the number of newly created codes
C – the total number of codes.

The lower the index score is, the lower the variety of codes and the reduction of their excessive number in the system is.

As mentioned, increasing components' commonality through standardization programs reduces manufacturing costs (Kota & Miller, 2000). The degree of commonality index provides a way to directly relate the degree of component commonality to various dependent variables such as total cost, work center load, and delivery performance (Collier, 1981). Thorsten and Abdelkafi (Blecker & Abdelkafi, 2007) review the commonality indices developed and identify their limitations in evaluating component commonality for mass customization. The authors propose a new commonality index called the Total Commonality Index (TCI) that considers generic bills-of-materials for mass customization. The TCI considers common components, must-generic items, and options to evaluate the overall commonality of a product family. It shows that an increase in common components and must-generic items leads to a significant improvement in commonality. However, product options have a minor contribution to commonality. The method proposed in this article has an advantage over previous indexes thanks to its universality. It can be used at the level of furniture sets, individual pieces of furniture, and their components. Its fundamental advantage is that it supports the design of technologically similar components.

CONCLUSION

Furniture manufacturer constantly add new furniture variants to their offer, which has the disadvantage of using an extensive and continuously increasing number of dimensional variants of furniture components. These variants exist as digital mock-ups of the products (Model-Based Definition) in the ERP production system and could be successfully used in newly designed furniture. However, designers constantly generate new parts in practice, sometimes duplicating previously produced ones. It is better not to increase the number of these elements excessively.

No indexes were found to determine the rationality of the dimensional decisions made. Some of the dimensional choices are permanent and unchangeable because of the current anthropometric characteristics of humans. Humans make other decisions that may be non-fully technological without an appropriate selection path. Recognizing this problem was the determinant for creating the tripartite index of technological goodness. The created index of technological goodness determines the degree of consistency in applying the selected design rule (selection of dimensional values from a specified numerical sequence or its multiples). Technological goodness can, therefore, be assessed at three levels: dimensional integrity within the universe of preferred dimensions for a single furniture unit or group of furniture, mutual similarity of furniture groups, and similarity of furniture codes.

The "technological goodness index" proposed has contributions across theory, science, and practice in furniture design.

1. In the field of theory, the index bridges the gap between aesthetics (pleasing dimensions) and technological efficiency (reduced production complexity). This contributes to a more unified theory of furniture design that considers both user experience and production realities.

2. In science, the index offers a new quantifiable metric to evaluate furniture design based on production efficiency and part optimization (a novel metric for Design Evaluation). This can be used in research to study the relationship between design choices and their manufacturing implications.

3. In practice, by incorporating the index into the design process, furniture manufacturers can create designs that are both aesthetically pleasing and production-friendly. This can lead to cost savings, reduced waste, and potentially faster production times. Using the index in employee incentive systems could motivate designers to consider both aesthetics and production efficiency in their work. Integrating the index with online furniture self-design platforms could guide customers towards dimensionally efficient choices, potentially streamlining the design and ordering process.

Overall, the "technological goodness index" appears to be a valuable tool that can improve the theory, science, and practice of furniture design by promoting designs that are both aesthetically pleasing and technologically efficient.

Further research aims:

Validation the effectiveness of the index in achieving its goals. This could involve testing it with designers and manufacturers to see how it impacts design decisions and production outcomes.

Integration with existing design software to provide real-time feedback on the technological goodness of a design.

Finding the right balance between aesthetics and efficiency. The index should not solely dictate design choices but rather be a tool to inform the design process.

Addressing these considerations can further develop and refine the "technological goodness index" to contribute to furniture design.

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