Morphological Comparison Between Two Model Groups of the Same Product Family Belonging to Different Price Levels

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Abstract

The relationship between aesthetically pleasing product forms and their sales success has long been analysed in industrial design. However, the link between product form and market positioning has attracted less attention. This study analyses the differences between the form of product models within the same product family, classified into high-end and mid-range products according to their price. Thirty 3D dining chairs files from five furniture brands were collected. Using the Product Phenetics approach and the morphological analysis software ProPheTA, the chairs in each group were converted into voxel-based models, aligned, and overlapped to obtain two product design spaces: the high-end product design space (HPDS) and the mid-range product design space (MPDS). The HPDS and MPDS were divided into three subspaces: backrest, seating, and legs. The volume, intersection and uniqueness ratios of the HPDS, MPDS, and subspaces were calculated to compare their spatial distribution. The results showed that HPDS is larger and has twice the morphological diversity of MPDS. As for the subspaces, in the seating one the most volume is shared by both design spaces, followed by backrest and legs, where there is more morphological diversity for the two groups. In the seating subspace, the HPDS reached 36% uniqueness morphology, whereas the MPDS scarcely reached 7% novelty. Thus, Product Phenetics identified morphological differences between products of the same family and different price, defining subspaces where making changes can represent an innovation and providing an efficient way to analyse product morphology from the early stages of product design.

Keywords: Conceptual Design, Design Space, Morphological analysis, Product Phenetics, Spatial Distribution

1. Introduction

In today's highly competitive global marketplace, products within the same category are strategically priced at different levels to cater to diverse consumer segments (Novo-Peteiro, 2022, Bansal & Maglaras 2009). Well-established and classic brands carefully position their product lines to capture different market shares (Bagajewicz et al., 2010; Ma, 2022, Zhang et al., 2023). Product portfolio may span from budget-friendly items to luxurious flagship products (Chen, 2023). This price variance can be manifested in multiple product attributes, including shape, material quality, colour, texture, craftsmanship sophistication, style, and packaging type, to name just a few. To foster emotional connections and enhance brand loyalty, accurately positioning the grade of the product in the minds of consumers in the most intuitive way has become an important direction of design (Ivanov et al., 2023; Wang, 2019). In this line, the morphological characteristics play a pivotal yet often under-explored role among these attributes. Product morphology has a vital importance in current product design, being especially critical for product categories where functionality is inherently tied to shape, such as in ergonomically sensitive design (e.g., Silviana et al., 2022; Lourenço et al., 2022).

The shape of a product, as the main component of consumer aesthetics, is decisive in setting product attractiveness, brand valuation and consumer preference (e.g., Wang et al., 2022). Consumers tend to correlate product visual shape with product quality, performance, and value (Zinco et al., 2021; Teichert et al., 2009). Furthermore, product shape conveys symbolic and cognitive messages, evoking certain emotions and perceptions (e.g., Artacho et al., 2010; Norman, 2004; Lee, 2007; Chitturi et al., 2019; Creusen et al., 2018). From a consumer perspective, aesthetic appeal, emotions and symbolic attributes are increasingly influential in purchasing decisions (Artacho et al., 2020, Gulgec, 2019). Many works relating product design and shape to purchase intention can be found in the literature (e.g. Kang et al., 2019; He & Ji, 2016). However, the role played by morphology in product categorisation and price setting has been the object of lesser study.

Product categorisation is the process of organizing products into specific categories or groups based on the characteristics they share (e.g., Ghiassaleh et al., 2024). Humans have the cognitive ability to holistically interpret a product and place it in a mental category along with products they find similar (Dagogo-Jack & Forehand, 2018). This categorization depends on the fluidity or complexity of the information processing that holistically conveys the design of a product. That process, in turn, will depend on the number of components a product has, the interactions between them and the level of novelty they convey (Kumar and Noble, 2016).

Thus, an excess of novelty could impair consumers' intuitive categorization and sense of familiarity as they lack referents to compare with. Therefore, the success of product innovation will not only depend on its creativity or degree of novelty, but also on the ease of the categorization process (Liu et al., 2017). Despite the importance of product categorization processes in the main differentiation and innovation strategies used in product development, the existing literature on this phenomenon regarding product shape design is still very limited (Sameti, 2022). The aim of this paper is to find out the role played by the shape of a product in establishing different price categories within the same product family.

The concept of Product Phenetics (PP) was first introduced by Artacho et al. (2016) and can be helpful in addressing this objective. Their work aligns with the principles of Design Spaces and inductive methodologies, positioning product morphology as a foundational element in the design process. They proposed a 3D Design Space framework encompassing the volumetric envelope of all digitised products within a given category. This framework is further divided into two subspaces: the Functional Invariance Space (FIS) and the Change Space (CS). The FIS represents the common volume shared by all product models, ensuring the preservation of essential functional attributes. In contrast, the CS denotes the regions where modifications can be made to enhance aesthetic appeal, emotional resonance, and ergonomic adaptability without compromising the product's core functionality (Artacho et al., 2016). This approach provides a structured way to explore the relationship between form and function, providing designers with a tool to innovate while maintaining functional performance. PP overcomes typical disadvantages of methodologies that divide the product into components and parts when analysing the shape (e.g., Kanse Engineering (Lu et al., 2024), Product Semantic (e.g., Sunstrum et al., 2024), Conjoint Analysis (Nag & Goswami, 2023), etc.), since it analyses whole shapes, which allows the holistic evaluation of the products, enhancing processing fluency and product categorization.

This research compares the morphology of two model groups within the same product family but positioned at different price levels using PP principles. The objective is to discover hidden or latent rules that might justify such a categorisation from a morphological point of view. To facilitate a more intuitive and efficient analysis, the authors have developed a voxel-based analysis module within the ProPheTA software (Artacho et al., 2024). This software comprises methods and tools which enable a detailed exploration of similarities and differences in product morphological features.

2. Material and Methods

2.1 Selection of a Sample of 30 Models Belonging to the Dining Room Chairs Product Family

In this study, a total of 30 dining chairs were sourced from five brands, and their respective market prices were collected. These chairs were available in the form of 3D models, which were downloaded directly from the brands' official websites and converted into STL format using SolidWorks 2021 software. During this process, any necessary repairs were carried out to rectify potential model imperfections. At the same time, each model was adjusted to its actual size.

2.2 Classify the Chair Models by Grouping Them into High-End and Mid-Range

The thirty chairs were divided into two groups (the high-end and mid-range groups) according to their prices, with fifteen models in each group. The price cutoff point was set at 1.500€; that is, the price of the chairs belonging to the high-end group was greater than or equal to 1500 €, and the mid-range group of chairs was cheaper than this price.

2.3 Models' Alignment Criteria Selection

When choosing the alignment point for the chairs, the product category was assessed from both a functional and an ergonomic perspective. Dining chairs are meant to support people while they sit. The seat cushion used for sitting, without being affected by the backrest and the legs, is the core component enabling the chair to carry out its main function. Thus, all models were aligned to the centre point of the seat cushion.

To pinpoint this centre point, the cushion's length was defined as the distance from its front edge to the connection with the backrest. Half of this length represents the geometric centre of the cushion, as shown in the left image of Figure 1. The vertical position of the centre point is set at the middle of the cushion's thickness, as depicted in the right image of Figure 1.

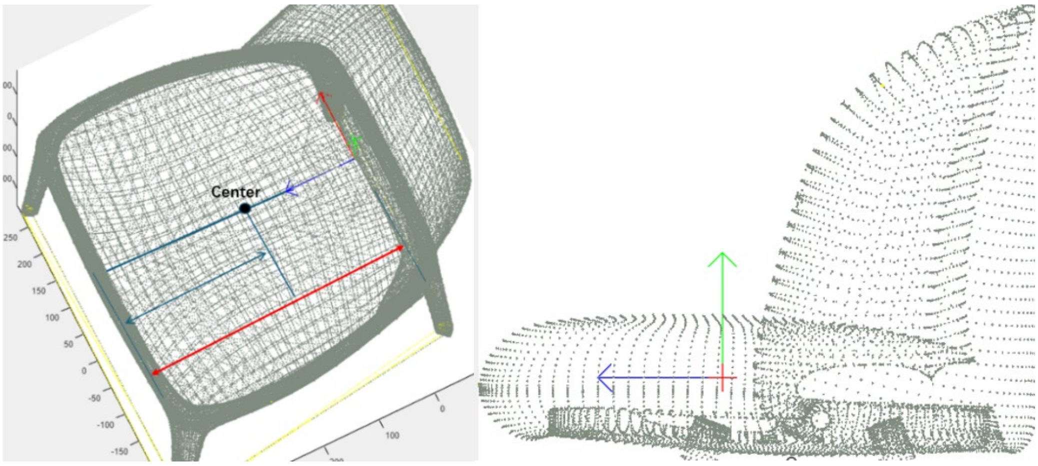

Figure 1. The centre of the seat cushion

2.4 Conversion of STL 3D Files to Voxel Models

After aligning all the models, they were converted into a solid spatial representation. To achieve this, solid voxels were employed, which are essentially small cubes. These voxels were arranged in a closely packed manner, shown in Figure 2, leaving no gaps until the entire volume within each STL file was filled. It is important to note that there is a trade-off in voxel size selection. A smaller cube size offers higher precision in the representation, but it also demands more computer resources. The side length of the voxels was set at 2.5 mm as a trade-off solution.

For this conversion task, the ProPheTA software was used (Artacho et al., 2024), as depicted in Figure 3. ProPheTA incorporates multi-threading technology, which enables it to harness computing resources effectively. This technological advantage allows for the efficient generation of these geometric bodies. As a result, the time required for model conversion can be significantly reduced to less than one hour. To ensure the smooth operation of ProPheTA during this process, it is advisable to use a CPU with at least eight physical cores and 32 GB of memory. This configuration helps optimise the software's performance and ensures accurate and timely model conversion for subsequent analysis.

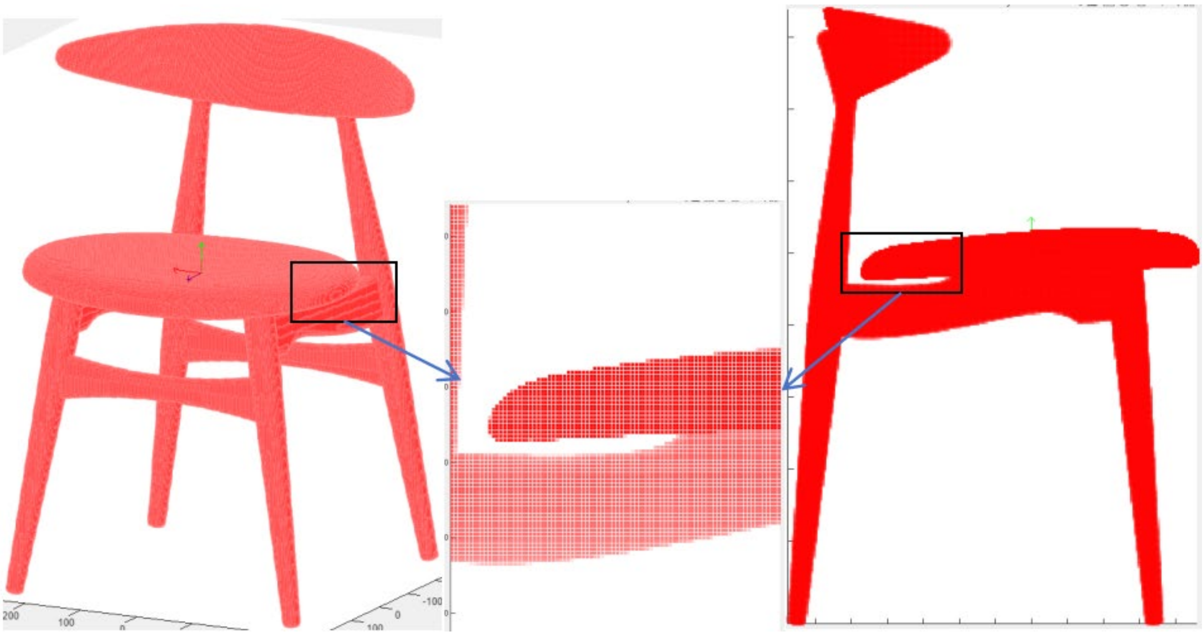

Figure 2. Model composed of voxels.

2.5 Product Design Space Definition for the High-End and Mid-Range Group of Chairs

Artacho et al. (2016) defined Product Design Space (PDS) as the total volume envelope encompassing all digitised and aligned models belonging to the same product family. It contains two subspaces: the Functional Invariance Space (FIS), consisting of the volume portion of space common to all shapes, and the Change Space (CS), where modifications can be made without affecting functionality.

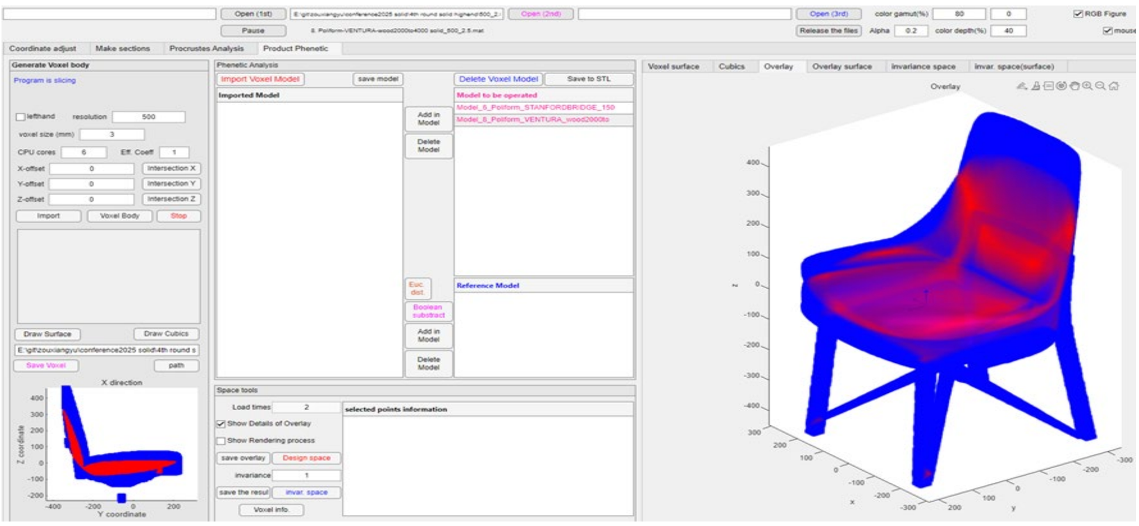

Figure 3. Interface of ProPheTA and its Product Phenetic analysis module.

Figure 3 illustrates the scenario after two chairs have been loaded. In the figure, the red areas represent the overlapping regions of multiple models, that is, the FIS, while the area in blue colour is the space without any overlapping, where the CS is.

After aligning and overlapping the chair models, the PDS for the two chair groups were determined: the 15 models belonging to the high-end group were aligned and superimposed to obtain the High Product Design Space (HPDS), and the same treatment was done for the 15 models in the mid-range group to get the Mid-range Product Design Space (MPDS).

2.6 Subspaces Definition by Cutting Models into Three Sections in Height

The two sets of design spaces were divided into three subspaces for research: Backrest, Seating, and Legs. The range of the Seating subspace was 65mm to -135mm on the z-axis (in height direction). The height and position of this subspace was chosen so that it would contain the seat cushion part of all 30 models. Figure 4 shows an example of cutting a single model.

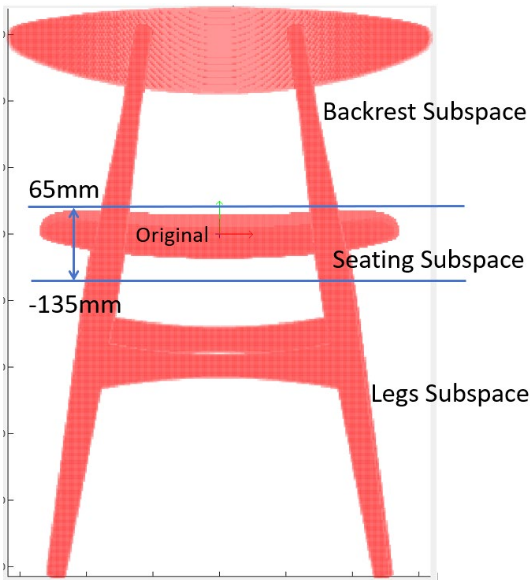

Figure 4. Cutting a chair into three sections: Backrest, Seating, and Legs subspaces.

Once the seating subspace was determined, the backrest and legs subspaces were obtained for both the HPDS and MPDS.

2.7 Morphology Comparison Between and Within Groups

By comparing the spatial distribution of HPDS, MPDS, and their subspaces, the strategies and design styles of dining chairs at different price levels could be intuitively analyzed. To do so, the volume occupied by the two design spaces and that of the defined subspaces were calculated. The volume was calculated by counting the voxels in each space and subspace. The volume unit in this study was 2.5^3 mm^3 (15.635mm^3).

The volume occupied by the resulting intersection of the two design spaces (HPDS ∩ MPDS) were calculated. Then, the intersection ratio (IR) for each design space and subspace, see

Expression 1 and 3, and the uniqueness ratio (UR), defined as the proportion of the volume of each design space and subspace that lies outside their intersection, see Expression 2 and 4, were calculated.

$$IR(HPDS) = Volume(intersect\ space)/Volume(HPDS) \quad (1)$$

$$UR(HPDS) = Volume(HPDS - intersect\ space)/Volume(HPDS) \quad (2)$$

$$IR(MPDS) = Volume(intersect\ space)/Volume(MPDS) \quad (3)$$

$$UR(MPDS) = Volume(MPDS - intersect\ space)/Volume(MPDS) \quad (4)$$

3. Results

The following results were derived after conducting experimental procedures and analyzing the data, as detailed in Section 2.

Figures 5 and 6 show the chairs classified as the high-end and mid-range price levels, respectively.

Figure 5. Fifteen more expensive chairs as the high-end group.

Figure 6. Fifteen cheaper chairs as the mid-range group.

Figure 7 shows the results of converting the triangle-based STL format models into voxel models and overlapping them into the two defined design spaces: HPDS and MPDS.

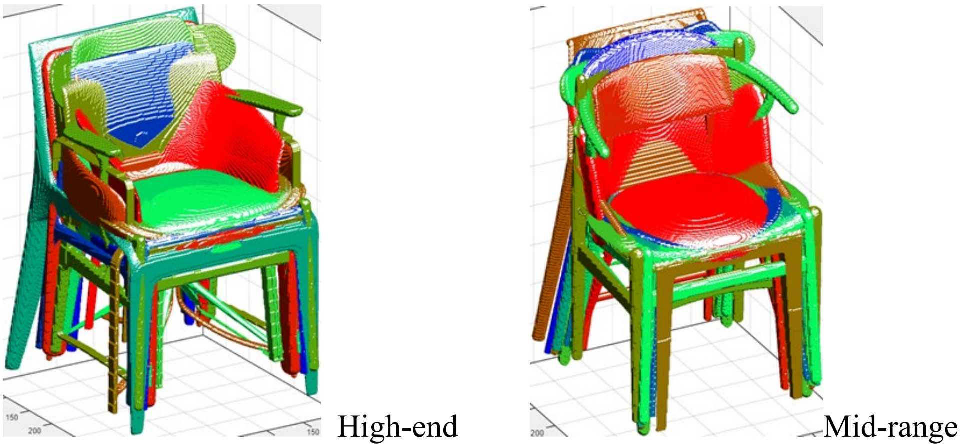

Figure 7. Design Space of High-end group and Mid-range group.

Figure 8 shows the three pairs of subspaces (Backrest, Seating, and Legs) for the two groups in different colours.

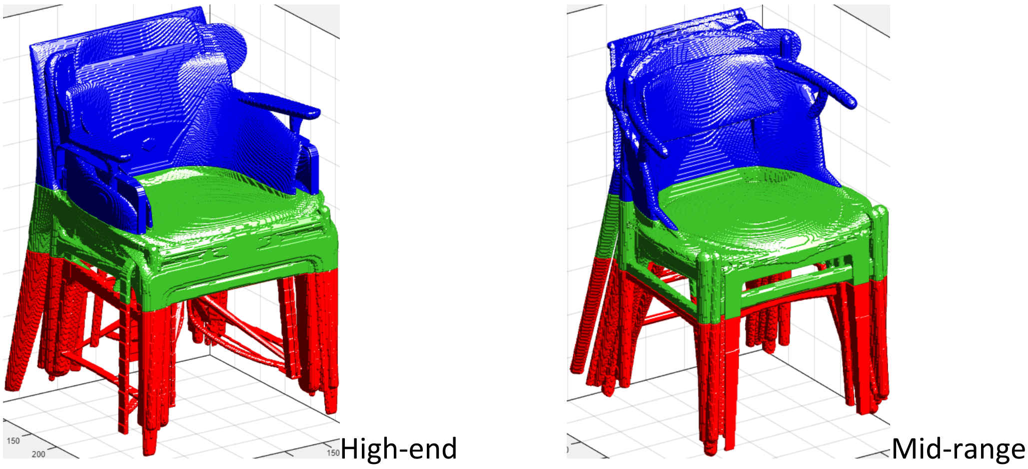

Figure 8. Upper, middle and lower sections of the Design Space.

Volumes and their distribution among the subspaces are shown in Figure 9. The resulting volumes of the two design spaces were 6.187.261 voxels for the HPDS and 4.517.057 voxels for the MPDS. So, the design space of the high-end group is much larger than that of the mid-range group.

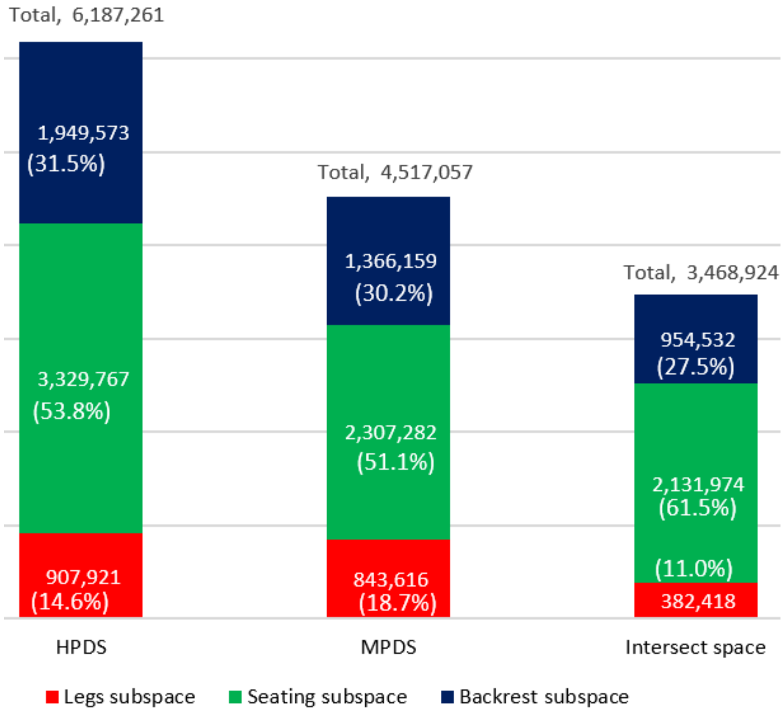

Figure 9. The total volume, volume of subspaces, & intersect space (Unit: voxel).

Interestingly, the volume distribution of the subspaces in the HPDS and MPDS is almost the same. The seating is the subspace with the largest volume, followed by the backrest, with the legs occupying the smallest volume.

Figure 10 shows the UR and the IR between the design spaces and among subspaces.

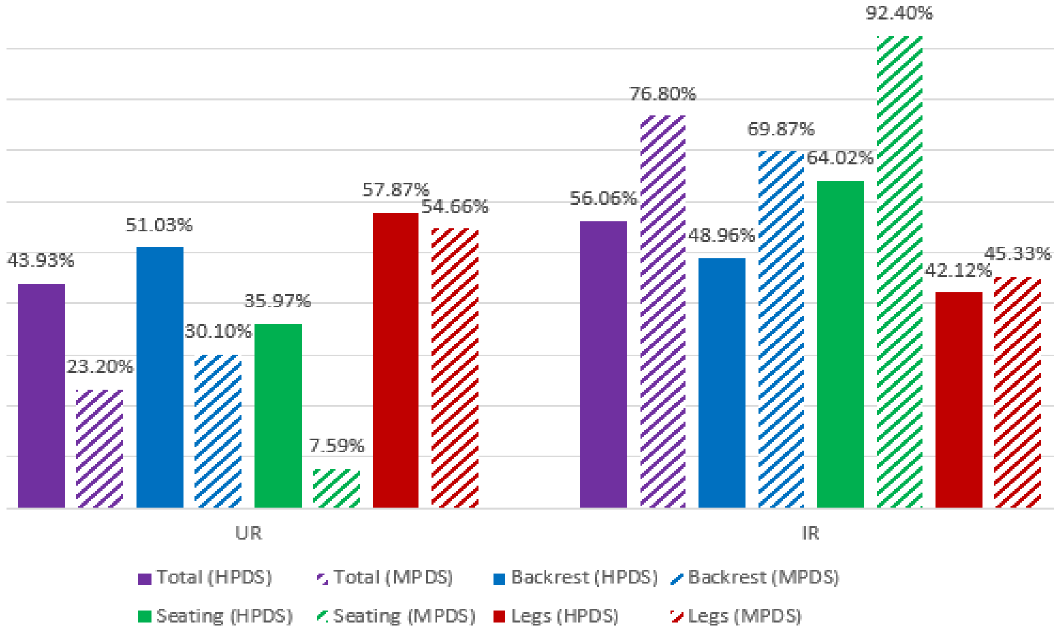

Figure 10. Proportional relationship between subspaces

Overall, the high-end group has twice the UR of the Mid-range group. In all the subspaces, the uniqueness is more significant in the HPDS than in the MPDS. It is worth noting that for the seating subspace, the UR of the mid-range group is very small (7.59%), approximately five times less than in HPDS. Interestingly, in the leg's subspace, the two groups have similar UR values. This subspace is the smallest one in volume but has the highest UR – see Figures 9 and 10. From a complementary point of view, the IR results lead to same conclusions by exploring the amount of common volume occupied by the two design spaces.

Figure 11 shows on the right the sum of the two backrest subspaces seen from the outside, and the left figure shows the intersection volume between the two backrest subspaces.

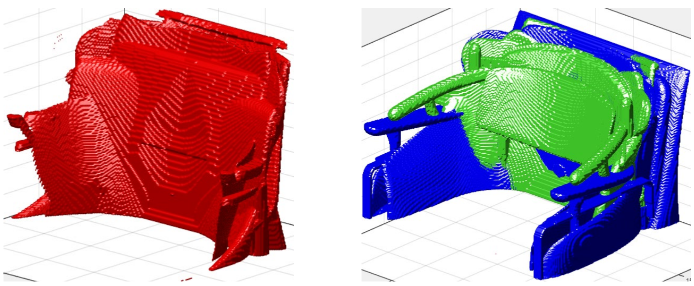

Figure 11. Comparison between the two groups' backs.

Figure 12 shows on the right the sum of the two seating subspaces seen from the outside, and the left figure shows the intersection volume between the two seating subspaces.

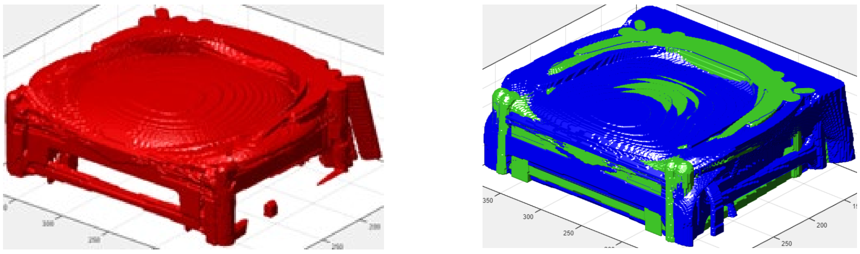

Figure 12. Comparison between the two groups' seating subspace.

Figure 13 shows on the right the sum of the two leg subspaces seen from the outside, and the left figure shows the intersection volume between the two leg subspaces.

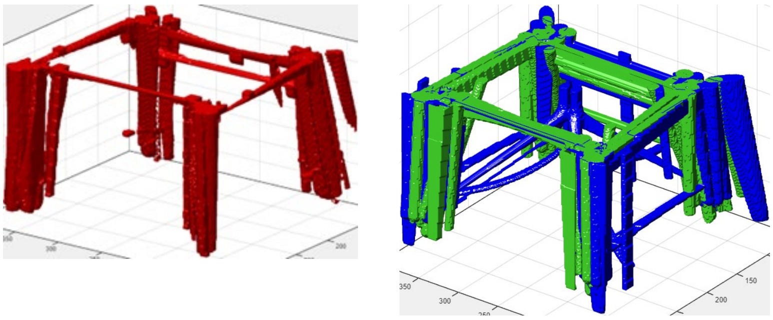

Figure 13. Comparison between the two groups' lower section.

By segmenting the model into three subspaces, the complex geometric structure of dining chairs is effectively decomposed to facilitate morphological analysis. From the perspective of the PP approach, the three subspaces exhibit different design strategies, and models at different price levels clearly demonstrate varying morphological styles.

4. Discussion

This study presents a novel approach to understanding the morphological differences between two model groups of the same product family with different price levels, using dining chairs as a case study. Product Phenetics and ProPheTA software applications provide a quantitative and systematic way to analyze product morphology and related design styles.

The Design Spaces definition of different product models belonging to the same product family highlights commonalities and differences and enables a more comprehensive and intuitive analysis. The segmentation of voxel-based models allows designers to quantify morphological differences easily. Moreover, defining different subspaces within the defined Design Spaces will enable designers to find innovation opportunities.

The HPDS is larger than the MPDS for the case study, and the high-end group has twice the UR of the mid-range group. However, the volumetric distribution between the different subspaces is practically the same. This fact could indicate that high-end models' differentiation is mainly based on introducing greater morphological variability, keeping chair's proportions and well-established design rules unchanged to guarantee product's functional performance.

These results are in line with previous works showing the key role played by shape in product design and innovation at present (e.g. Tang & Cui, 2014; Yang et al., 2023).

Regarding the subspaces defined, compared with the mid-range group, the morphological novelty introduced by the high-end group is significantly larger in the seating subspace, showing that this subspace is vital to making differences among the chair models. That also means there is much room for innovation in the seating subspace shape for the mid-range group. The leg subspace is the smallest in volume but has the highest UR in both design spaces, reaching practically the same value. This result might be related to designers' high degree of freedom in solving this subsystem functionally, leading to higher variability in shape proposals.

Despite the explorative nature of the study, the findings could have several practical implications. This research emphasizes systematic study of product's morphology and market positioning in product design, reflecting how designers employ different morphological strategies to cater to various market segments. The Product Phenetics approach could be used to better understand the morphological differences between products at different price levels, which could be relevant for designers and marketers to optimize their design categorization strategies (Marcelinawati & Indrasari, 2021). Companies can use this approach to better differentiate their products in competitive markets by focusing on keeping innovative morphological changes easy to understand and perceived by users. In addition, Product Phenetics opens new avenues of research in morphological analysis and product categorization, providing insights to better deal with innovation, user perception, and market performance.

This current study is limited by the small sample size and the fact that it has been tested in one product category with only two range levels. Moreover, product range segmentation was established in an arbitrary way, as well as the subspace definition, so more rigorous ways of performing these tasks are required. Also, the research only focuses on morphological differences. It does not fully consider other factors, such as material quality, manufacturing costs, and brand image, which are also closely related to product price and market positioning (Rahayu et al., 2023; Amron, 2018). Thus, future research should apply PP to different product families, expand the sample size, and include a broader range of product categories.

Notwithstanding these limitations, the study provides a new perspective for designers and manufacturers to understand how different price levels and morphology could influence product design and how to optimize their design and marketing decisions accordingly.

5. Conclusion

This study successfully employed Product Phenetics (PP) to analyze the morphological differences between high-end and low-end dining chairs. PP has proven useful to understand the morphological differences between two model groups of the same product family with different price levels. The application of ProPheTA's voxel-based approach, and the subspace definition provided a quantitative and systematic way to analyze product morphology and related design styles or strategies.

The results of this work show that each product class differs in total volume and occupancy, but the internal distribution across subspace remains consistent. Overall, the high-end group has higher uniqueness, having more morphological variety in all the studied subspaces. The subspaces approach has allowed us to find innovation opportunities, as is the case for the seating subspace of the MPDS. The leg subspace is the smallest but has the highest uniqueness in both HPDS and MPDS, showing no differences between them. These findings have significant implications for understanding how morphology entails relevant information that PP is able to unveil, helping designers and marketers gain insights when it comes to design product portfolios.

With continuous improvement and further research, the PP approach could be a promising method to improve product design and development, enabling designers to create more market - oriented and innovative products from the early stages of product design, setting morphology as a new design starting point.

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