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DOCTORAL THESIS

Contributions to the development of co-created products and products with personality

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Content

Appendices

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CHAPTER 1. THE CURRENT STATE OF RESEARCH ON THE CREATIVE DEVELOPMENT OF CO-CREATED PRODUCTS

1.1 Conceptual Foundations of Co-Created Product Development

According to the specialized literature, co-created products are the result of active collaboration between research and development teams and consumers, resulting in functional, aesthetic, and technological products designed to meet users' needs and expectations. The concept of co-creation involves the continuous engagement of the consumer in the design process, which ensures a product that is better tailored to their needs and an enhanced user experience. Based on this concept, co-creation relies on the idea that involving the customer not only helps in creating more innovative and market-adapted products, but also contributes to reducing research costs. This approach was first introduced in Europe four decades ago and gained popularity as new technologies and marketing strategies evolved. Co-creation practices are grounded in the idea that users can become active co-creators, significantly contributing to the development and customization of products. The literature identifies four distinct forms of co-creation: collaborating, tinkering, co-designing, and submitting.Co-creation offers multiple benefits, including increased customer satisfaction and improved market success by aligning consumer needs with product specifications. A general objective of this process is to encourage the consumer to act as a partner in the design process, contributing with creativity and passion—from refining an existing product to generating new concepts. This collaboration enhances customer satisfaction and the level of personalization in the consumer experience.

1.2 Structure and classification of co-creation processes

Following an analysis of the current state of research, it has been established that the co-creation process involves several stages, ranging from the collection of ideas and suggestions to the selection of the most valuable contributions from consumers. The fundamental shift in the design process lies in the transition from a model where the designer simply meets consumer needs, to one of active collaboration between the two parties. This model fosters collective creativity, which leads to innovation and product personalization. Within the co-creation process, stages that involve collaboration between designers and users are identified, thereby forming new areas of collective creativity. Co-creation is often confused with co-design, although the latter refers to a specific act of collaboration between designers and consumers, whereas co-creation encompasses multiple approaches (see fig. 1.4; 1.5). The success of the product development process is evaluated based on essential information about customer needs and their corresponding solutions. Active consumer involvement is considered a key factor in fostering creativity and innovation.

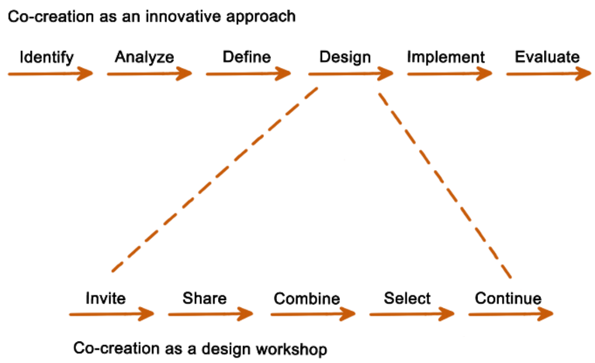


Fig. 1.4.Stages of the Co-Creation Process (Adapted from De Koning et al., 2016)

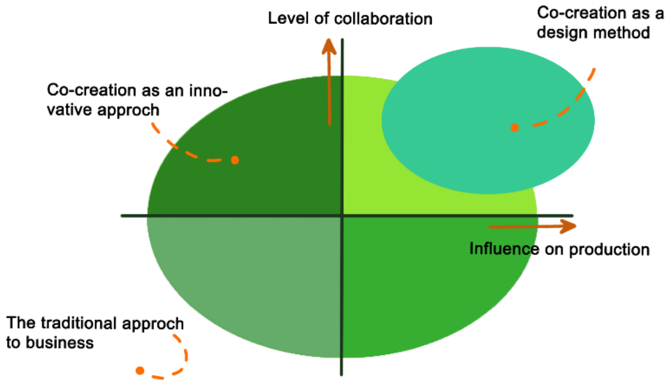


Fig. 1.5. The Co-Creation Spectrum (Adapted from De Koning et al., 2016)

Researchers in the field have classified co-creation into different categories involving active collaboration between consumers and companies, with various forms such as sponsored co-creation and automatic co-creation (O'Hern and Rindfleisch, 2008). Hybrids of these forms have been developed on websites targeting e-commerce, allowing buyers to simulate products and how they can be used (Zwass, 2010).

Some authors consider five types of co-creation related to (1) personalized offerings, (2) real-time self-service, (3) mass customization, (4) co-design, and (5) community design (De Koning et al., 2016). The strategies adopted by companies in the co-creation process enable customers to actively participate in product development, providing variable control over selection and contributions (van Westen and van Dijk, 2015).

1.3 Current state of the use of methods, techniques, and tools for stimulating creativity in the development of co-created products

It is considered essential for manufacturers to be open to allowing adjustments from customers, thereby improving their satisfaction and reducing the gap between customer requirements and product specifications. Mass production is often insufficient to meet individual customer needs, and solutions for personalization and active involvement are crucial. In the co-creation process of products, three fundamental aspects are analyzed: customer needs, production capacity, and engineering constraints. By combining several methods, such as the Kano Model (Mikulić, 2007; Lina He et al., 2017), which is used to evaluate customer satisfaction, and QFD (Quality Function Deployment), employed to translate customer desires into technical requirements (Akao, 1990; Akao, 1994; Mizuno and Akao, 1994), the design process of products is improved. When combined with the Kano Model, QFD enhances product design. FMEA (Failure Mode and Effects Analysis) is used to identify and correct defects in co-created products, involving the customer in the risk assessment process and improving product quality (Koomsap and Charoenchokdilok, 2016).

The co-creation process is an innovative method that actively involves consumers and other stakeholders in product development to better respond to their needs. Co-creation is also associated with concepts such as open science and open innovation, which promote transparency and collaboration between researchers and the public. These concepts are supported by platforms like Citizen Science (Irwin, 1995), which involve the general public in scientific research. The benefits of co-creation include greater consumer engagement in product development, which can lead to increased satisfaction and market differentiation. Companies are beginning to recognize the importance of customer relationships, moving beyond the traditional product-centered view. They open their doors to ongoing negotiation with customers, focusing on the importance of interaction. Through the principles of co-creation, companies save time and resources in market research, as well as understanding customer expectations. Active consumer involvement at all stages of the creation process helps meet their needs.

1.4. Benefits associated with co-created products

Consumer involvement in product development has become essential in today's market context, where differentiation through co-creation offers a competitive advantage. Companies are moving away from a product-centered vision and beginning to build direct relationships with customers, based on dialogue, access to information, transparency, and a balance between risks and benefits. Active consumer participation enables the rapid collection of relevant information about their needs and expectations, reducing research costs and accelerating the innovation process (Prahalad & Ramaswamy, 2004). This collaboration leads to increased customer satisfaction, as customers feel valued and involved in the creation of a product tailored to their own experience. In the co-design process, the consumer becomes an active partner of researchers and designers, contributing significantly to the development of relevant and personalized solutions. Co-creation leads to greater consumer satisfaction, as customers feel their opinions directly contribute to the development of a product that better meets their needs. This process transforms the relationship between designer, researcher, and user, positioning the user as the "expert of their own experience" (Sanders & Stappers, 2007), influencing the development of concepts and ideas.

CHAPTER 2. THE CURRENT STATE OF RESEARCH ON THE DEVELOPMENT OF PRODUCTS WITH PERSONALITY

2.1. Definition and classification of product personality

In contemporary marketing, adapting the consumption experience is essential for strengthening the relationship between the product and the user. Three distinct practices—personalization, customization, and product personality—aim to achieve this goal, although they present notable conceptual and operational differences.

Product personalization represents a strategy where the company adapts the product or message toward a consumer or segment, using demographic and behavioral data. Customization, on the other hand, is initiated directly by the user, who explicitly specifies their preferences with the aim of receiving a product tailored to their personal needs. Thus, the customer becomes a co-creator, and the resulting product is unique and indispensable. According to Stan Davis (Davis, 1990), this involves adapting mass-produced products to individual needs, marking an essential difference from personalization. Product personality involves designing the object with recognizable human traits, facilitating the consumer's affective identification with the product, thereby contributing to the creation of a deep emotional attachment and transforming the object into an identity symbol. These three approaches represent strategic responses by companies to the increasing demand for individualization of consumption, each relying on different dimensions of the customer's subjective experience: belonging, control and empathy.

The process by which a customer is attracted to a product is complex, influenced by individual perception and identification with human traits transferred to the object. The concept of product personality entails integrating a set of human characteristics into the design of the object so that it becomes unique, recognizable, and capable of generating emotional attachment. Personalization, supported by market research, aims to place the consumer at the center by offering products that symbolically express their self. Experts in the field define product personality as a profile of human traits attributed to objects by users to differentiate and humanize them. The product, initially neutral, gains a personality through repeated interaction with the user, becoming an element with which the user emotionally identifies. This relationship is built on the compatibility between the personalities of the two entities: human and object (Stolterman, 1997; Jordan, 1997; Kleine et al., 1993).

Product perception is influenced by individual factors such as attention, interest, experience, and curiosity, as well as by the user's emotional history. Product characteristics (color, shape, functionality) and the product's overall character (an aggregate of characteristics) can contribute to the formation of an emotional bond. Thus, product personality becomes a means of reflecting personal identity, symbolizing and complementing the consumer's self.

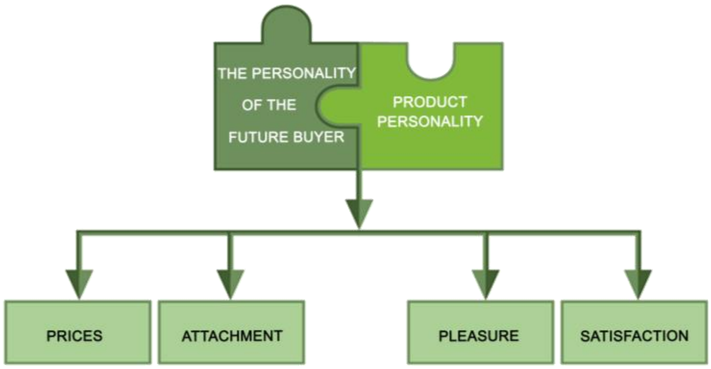


Fig. 2.1. Personality Congruence Theory (Adapted from Patrick Jordan, 1997)

The consumer's personality is reflected in the design of successful products (Jordan, 1997). This aspect is confirmed by the compatibility between the user's personality and that of the product, which leads to increased emotional attachment and a favorable evaluation of the product. This highlights individuals' tendency to prefer products congruent with their self-image (Aaker, 1999; Govers and Schoormans, 2005).

Products congruent with personal identity can strengthen the sense of self (see fig. 2.1), while lack of congruence can lead to identity dissonance (Kleine et al., 1993). A product's personality primarily derives from supra-functional characteristics such as appearance, feel, branding, and symbolic meaning, which profoundly influence user perception and attachment (McDonagh and Weightman, 2003).

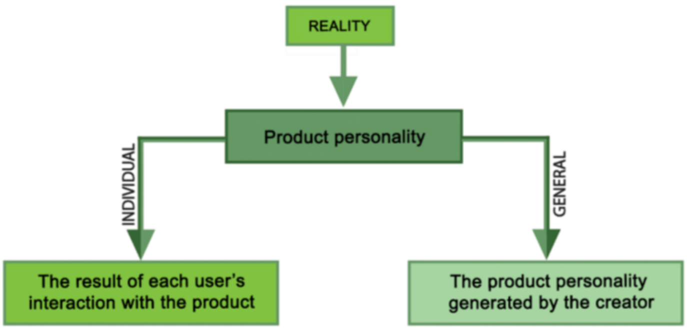


Fig. 2.2. The relationship determined by the product's personality (Adapted from Dumitrescu, 2013)

Following an analysis of how the emotional relationship between the user and the product contributes to its success and durability (Fig. 2.2), it was found that the affective value of a product is often more important than its material value, with emotional loss generating a deep attachment (Schultz et al., 1989). Attachment is facilitated by personality congruence between the user and the product, although this relationship is not time-invariant, being influenced by factors such as fashion.

In the specialized literature, modeling product personality represents an increasingly consolidated endeavor, integrating significant contributions and developing models. An important step toward standardization was achieved through a generalized and efficient evaluation scale, constructed based on over 1100 identified traits, which were reduced by semantic aggregation to 20 relevant terms. This scale was tested on automobiles and other products, demonstrating the ability to compare both products within the same category and across different categories, thereby providing a useful tool for creating a reference base for designers (Govers and Mugge, 2004).

2.2. Product development based on user experiences

2.2.1. Defining the concept of user experience

Over the past two decades, the concept of "experience through design" has evolved to become a central element in the development of products and services. It is not limited to the aesthetics of the product but also includes how it interacts with users, providing them with a pleasant and memorable experience. According to the studies of Hassenzahl and Tractinsky (2008), experience through design is the result of the interaction between the user and the product, generating emotional and cognitive responses, with an emphasis on user satisfaction, pleasure, and value. Additionally, Normann and Ramirez (1993) argue that design should create an environment that facilitates effective interaction between the user and the product, taking into account their needs and desires.

2.2.2. Classification of experience through design

Experience in design is approached through four essential dimensions: usefulness, pleasure, meaning, and identity (Hassenzahl, 2008). Each dimension emphasizes a distinct aspect of the user experience: usefulness focuses on satisfying the user's needs and goals; pleasure relates to emotional and aesthetic components; meaning describes the personal value the user attributes to the product; and identity reflects how the product aligns with the user's values and personality (Hassenzahl, 2008). Experience can be classified into three levels: utilitarian experience, aesthetic experience and symbolic experience. These distinguish between experiences related to the product's functionality, those related to visual and tactile perceptions, and respectively, the cultural or symbolic connotations that the product may generate (Forlizzi and Battarbee, 2004). Additionally, experience is classified by its nature as either accidental or designed. Accidental experience occurs when designers do not pay enough attention to the user's interaction with the product, resulting in a less controlled experience that generates variable emotions, positive or negative. On the other hand, designed experience is the result of a deliberate process of creating a product that induces pleasant emotions and satisfaction (Andrei Dumitrescu, 2013).

2.2.3. Emotional relationship with the product

The user's emotional response is seen as a result of the interaction between the individual and the product, influenced by the context of the interaction, the individual's personal traits, and the product's characteristics. Person (2003) suggests that a user's concerns are determined by these interactions, while Donald Norman (2004) argues that the emotional aspect of design can be even more important than a product's functionality when it comes to its success. Factors that can reduce user satisfaction include the perceptual wear of the product and its comparison with other products on the market. Such comparisons can trigger feelings of confusion, but can also influence the consumer's emotions if the chosen product is considered better than the alternatives.

2.2.4. Analysis of emotion typologies

Emotion typologies can be classified based on the type of feelings they evoke. Desmet (2002) proposed a tool called "PrEmo," which quantifies the emotions transmitted by products using animations that express both positive and negative emotions. These emotions are divided into two main categories: negative (e.g., indignation, contempt, disgust) and positive (e.g., desire, pleasure, inspiration). His study suggests that there is no direct relationship between design and the emotion generated, but the product's meaning to the customer is essential. Jan Jacobs (2019) adds another classification of emotions, dividing them into spontaneous emotions, designer-projected emotions, and advertising-induced emotions. Spontaneous emotions are influenced by personal experiences, while projected emotions are deliberately incorporated in the design process. Advertising creates superficial emotions around the product. Patrick Jordan proposes another classification based on four levels of pleasure: physical, social, psychological, and ideological. Understanding these emotions is essential for designers, as it allows them to create products that evoke positive emotions and avoid negative reactions, thereby contributing to a more satisfying user experience.

2.3. Current state of research on the use of methods, techniques, and tools for the development of products with personality

2.3.1. Methods for assessing human personality

Methods for assessing human personality can be classified into: (1) projective methods, (2) subjective methods and (3) psychometric methods. Based on these, various techniques, methods, and tools have been developed for evaluating product personality, among which the most important are presented as follows.

2.3.2. Scenario method for evaluating product personality

The scenario method represents an alternative to traditional surveys, being effective in obtaining contextual insights into participants' opinions and behaviors through the description of hypothetical situations. It allows respondents to express normative views within a narrative framework, fostering a deeper understanding of attitudes towards various social contexts (Finch, 1987). Building on this approach, the correlation between the personality of the user and that of the product is explored, based on the personality congruence theory. It is thus highlighted that products perceived as having a personality congruent with that of the user generate a stronger attachment (Govers and Mugge, 2004).

2.3.3. Psychometric method for evaluating product personality

Some specialized studies have analyzed how designers can convey a product's personality through its visual appearance, examining whether users can recognize the design intention by assigning ratings (Pascalle Govers, 2004). The analysis of shapes and colors used in the design process shows consistency between the visual language and users' perceptions, confirming the effectiveness of strong traits and suggesting difficulties in distinguishing between the other two characteristics. The research is based on the product personality model developed by Govers and Schoormans, incorporating the idea that people infer personality traits from visual appearances. The design process unfolds in three stages: defining the product's personality, gathering information through portrait analysis, and applying visual patterns. The activity involves exercises in deducing personality from images and transforming observed traits into basic visual rules (Govers and Schoormans, 2005).

2.4. Benefits associated with products with personality

Significant advantages associated with product development include four essential directions: commercial success, sustainability, increased visibility, and consumer education. Integrating personality traits compatible with those of users enables designers and manufacturers to create innovative products that satisfy emotional needs, thus contributing to consumer loyalty and product recommendations within close social circles. The typological variety of users can be addressed by developing multiple versions of the same product, offering freedom of choice. The product's personality also plays an important role in promoting sustainability. Emotional attachment determines users to keep products for a long time, repair them, and delay replacement, which reduces resource consumption and environmental impact.

CHAPTER 3. CONCLUSIONS REGARDING THE CURRENT STATE OF RESEARCH IN THE CREATIVE DEVELOPMENT OF CO-CREATED PRODUCTS AND PRODUCTS WITH PERSONALITY

Current research highlights the potential in designing modern products tailored to users' needs. A central element identified is the symbolic value of the product, which significantly influences purchasing decisions through emotional impact and association with aesthetic, cultural, or identity-related values. Relevant conclusions can be drawn regarding two major directions: co-creation and product personality.

A. Development of co-created products

Among the most effective co-creation methods identified in the literature are: the Kano method, QFD, the "mental image" DFC-DBC, FMEA, the GoNano principles, and "Open Innovation" models. These facilitate the translation of customer expectations into concrete product features. Direct consumer involvement is essential for the success of co-created products, which result from efficient collaboration between designers, engineers, and users. The benefits of these methodologies include:for producers - better market understanding, risk reduction, resource optimization, and increased customer loyalty; for consumers - more relevant products, a sense of involvement, and an enhanced experience. There is a gap in the specialized literature regarding concrete tools that facilitate user participation, especially for complex products where expert involvement is also necessary. Current approaches mainly target simple products (e.g., consumer goods, IT applications) without a clear structuring of methods based on product complexity.

B. Development of products with personality

1. Relevant methods for determining product personality include: the Jordan model, the Dumitrescu model, surveys, experience-based design, psychometric methods, and scenarios. These help designers understand the perceptions and emotions generated by the product.

2. These methods emphasize the user's perspective and provide valuable insights about expectations related to identity and expressiveness, guiding design choices in terms of shapes, materials, and functionalities.

3. The benefits are significant for both parties: designers create durable and relevant products, while consumers find products that express their personality, saving time and money and contributing to more responsible consumption.

The congruence theory, which states that users prefer products aligned with their own personality, remains a central framework but is also contested. Critics point out the oversimplification of the human-object relationship, its limited relevance for functional products, and the tendency toward overgeneralization. Proposed alternatives include factors such as aspirations, emotional attachment, and situational influences.

CHAPTER 4. RESEARCH-DEVELOPMENT DIRECTIONS, MAIN OBJECTIVE, AND METHODOLOGY WITHIN THE PHD THESIS

4.1. RESEARCH-DEVELOPMENT DIRECTIONS

Based on a detailed evaluation of the specialized literature and relevant case studies, necessary and timely research directions have been formulated within the doctoral thesis framework, as follows:

- The development of mathematical models and the design of demonstrative case studies applicable to the creation of co-created products and products with personality. This allows for an evolutionary approach to product requirements and/or characteristics, as well as a dynamic approach to their historical evolution over relatively long periods of time, based on the knowledge and application of the laws of temporal evolution of technical systems and the laws of temporal evolution of product requirements and/or characteristics;
- The conceptual and detailed design of a methodology for developing co-created products, accompanied by the creation of case studies to demonstrate its applicability;
- The development and definition of models and concepts regarding co-created products based on the classification of products into multiple categories, depending on the level of involvement of expert groups and/or users;
- The development of methods, techniques, tools, and applications for realizing co-created products where experts and/or users can intervene in all stages of product development;
- The development of tool-applications as case studies for validating the proposed concepts, exemplifying co-development of a product, including stages such as competitive co-design, functional co-design, conceptual co-design, architectural co-design, and detailed co-design;
- The elaboration of a new model for evaluating product personality that also considers aspects related to the mood and comfort induced in the user, starting from the shortcomings and controversies related to the existing theory of product personality congruence present in the specialized literature.

4.2. Research hypotheses

One of the most important hypotheses of the research in this thesis concerns the fact that user requirements, product characteristics, and the product itself evolve over time according to certain laws that must be understood and applied in order to forecast the next generation of products. Based on the laws of evolution of technical systems found in the specialized literature, laws of evolution for requirements and laws of evolution for characteristics can be formulated. Another major hypothesis refers to the degree of co-creation depending on the type of product, and starting from this, products have been divided into seven classes in which, based on complexity, co-creation can involve groups of experts and/or groups of clients or end users.

4.3. MAIN OBJECTIVE OF THE RESEARCH AND DEVELOPMENT ACTIVITY

Considering the conclusions drawn, the main objective of the doctoral activity is established as follows: *The development of a methodology for the creation of co-created products based on a set of appropriate methods, techniques, tools, and applications, along with a new model for evaluating product personality that includes aspects related to the mood and comfort induced in the user, with the aim of increasing customer satisfaction.*

4.4. RESEARCH AND DEVELOPMENT METHODOLOGY

To achieve the main objective of the doctoral thesis and the specific objectives, a research methodology is proposed based on theoretical and applied developments, the conceptual and detailed design of a new methodology, and validation through case studies and application on certain products of the developed theoretical elements. Thus, the research methodology applied within the doctoral thesis takes into account its interdisciplinary nature and is structured into two stages: a critical-constructive analysis of the current state regarding co-created products and the development of an original methodology for their design and evaluation of product personality. The research combines qualitative and quantitative methods, involving advanced tools such as TRIZ, QFD, the Kano model, and applications developed by the author, validated through case studies and diverse samples of experts and end users. The entire approach is aligned with level 8 EQF/CNC, aiming to deepen the theoretical knowledge and the applied development of scientific understanding.

4.5. LIMITATIONS OF THE SCIENTIFIC RESEARCH CONDUCTED WITHIN THE DOCTORAL THESIS

It can be stated that the most important limitations of the scientific research conducted within this doctoral thesis refer to the influence of the socio-cultural context and the behavioral differences among users.

CHAPTER 5. CONTRIBUTIONS REGARDING THE DEVELOPMENT OF MATHEMATICAL MODELS FOR THE EVOLUTIONARY STUDY OF CUSTOMER REQUIREMENTS AND PRODUCT CHARACTERISTICS

In the specialized literature, there are various models for evaluating product requirements and characteristics, most of which approach them from a static perspective. However, for the development of innovative products—especially co-created ones—an evolutionary approach is required, one that considers changes over time in customer requirements and product characteristics. The author proposes both static and evolutionary models, each with specific applications, taking into account their advantages and disadvantages depending on the typology of the products analyzed. Each proposed model has its strengths and limitations, but all are valuable within the context of a co-created product development methodology.

5.1. EVOLUTIONARY MATHEMATICAL MODELS OF THE IF-KANO TYPE

5.1.1. Model No. 1. The Two-Dimensional Vector Model

1a. Static Two-Dimensional Vector Model

Within this model, each requirement C_k is defined based on its importance to the client i_k and the frequency with which the client requests this feature, f_k. To apply the model, the two quantities — intensity and frequency — are normalized:

$$\mathrm{I_k} = \frac{i_k}{\sum_{k=1}^{n} \mathrm{i_k}} \in [0,1];\ \mathrm{F_k} = \frac{f_k}{\sum_{k=1}^{n} \mathrm{f_k}} \in [0,1] \tag{5.1}$$

where i_k and f_k represent the raw values of importance and frequency, respectively, and I_k şi F_k represent the normalized values of these quantities.

In this way, each requirement C_k can be expressed vectorially as follows:

$$\overrightarrow{C_k} = (I_k, F_k) = I_k \cdot \vec{i} + F_k \cdot \vec{j} \quad (5.2)$$

1b. The Evolutionary Bidimensional Vectorial Model

This new model has the advantage of enabling the study of how customer requirements and the associated characteristics/specifications evolve over time. At the same time, it can be used for the composition (fusion) of requirements by reconsidering the importance for the customer i_k and the frequency with which the customer requests the characteristic f_k, respectively the normalized values I_k and F_k, for a requirement/characteristic C_k' resulting from the combination of other n requirements/characteristics C_1, C_2, ..., C_n. In this case, equation (5.2) becomes:

$$\overrightarrow{C_k(t)} = (I_k(t), F_k(t)) = I_k(t) \cdot \vec{i} + F_k(t) \cdot \vec{j} \quad (5.7)$$

To establish the dynamic model, an adaptation and extension of the laws of requirement evolution proposed by Vladimir Petrov (Petrov, 2002) is suggested, as follows:

Law no. 1: The Law of Requirement Idealization

According to this law, customer requirements continuously evolve toward an idealization of the product, which can be evaluated using various indicators: flexibility, degree of human involvement, controllability, system multiplication, the nature, type and dimensionality of system functions, system complexity, density of component elements, evolution from macro scale to nano scale, transparency of components, and the number of colors used.

Law no. 2: The Law of Increasing Requirement Dynamics

This law emphasizes that the speed at which product requirements and characteristics change has increased exponentially in the past 10–20 years and continues to rise. According to the Kano model, initially attractive features become common over time, being recognized by both competitors and customers, thus transforming into performance characteristics and eventually into basic features. This phenomenon drives the evolution of customer requirements, which necessitates a thorough analysis of the relationship between technology, customer requirements, and product characteristics. The product life cycle, described in both its shortened and extended forms, follows an S-curve that includes four phases: introduction, growth, maturity, and decline.

Law no. 3: The Law of Requirement Interrelation

As the product evolves, positive or negative correlations emerge between customer requirements.

Law no. 4: The Law of Fusion (Composition of Requirements)

As the product and the technology incorporated in it develop, two or more requirements can merge, resulting in a new requirement.

$$C_p = \bigcup_{k=1}^{m} C_k \quad (5.10)$$

Law no. 5: The Law of Specialization of Requirements

As the product and the technology incorporated in it develop, some requirements become exclusive to that specific product.

Law no. 6: The Law of Emergence of New Requirements

As the product and the technology incorporated in it develop, new customer requirements arise regarding that product or for a broader group of similar products to which it belongs.

5.1.2. Model no. 2. The Complex Bidimensional Model

To eliminate the disadvantages of Model 1, the complex model is proposed, in which each requirement C_k can be expressed as a complex number where I_k is the real part and F_k is the imaginary part:

2a. Complex Two-Dimensional Static Model

In the case of the static two-dimensional model, using complex number theory, at any given time *t* we can write:

$$C_k = (I_k, F_k) = I_k + F_k \cdot i = |C_k| \cdot \left(\frac{I_k}{|C_k|} + i\frac{F_k}{|C_k|}\right) = \sqrt{I_k^2 + F_k^2} \cdot [cos\alpha + i \cdot sin\alpha] = \sqrt{I_k^2 + F_k^2} \cdot e^{i\alpha}$$

(5.12)

where $|C_k|$ represents the modulus of the complex number C_k, and the angle α can be expressed by the relation.

2b. Evolutionary Complex Two-Dimensional Model

In the case of the evolutionary complex two-dimensional model, each requirement is conceived as time-variable,$C_k(t)$. The shift of a requirement from one category to another can be easily modeled as:

$$\Delta C_k = |C_k(t_1) - C_k(t_2)| = \sqrt{(I_{k1} - I_{k2})^2 + (F_{k1} - F_{k2})^2} \quad (5.15)$$

Using this model, the composition (fusion) of two requirements can be easily modeled by multiplying complex numbers:

$$C_k \cdot C_q = (I_k + F_k \cdot i) \cdot (I_q + F_q \cdot i) = |C_k \cdot C_q| \cdot e^{i(\alpha_k + \alpha_2)} = |C_k \cdot C_q| \cdot [\cos(\alpha_k + \alpha_q) + i\sin(\alpha_k + \alpha_q)] = I_k' + F_k' \cdot i \quad (5.16)$$

in which $I_k, F_k, I_q, F_q \in [0,1]$.

This can be easily generalized for the composition (fusion) of *n* requirements:

5.1.3. Model No. 3. Three-Dimensional Vector Model

For situations where it is necessary to also consider a third dimension, for example the probability of detecting a latent requirement, P_m, a three-dimensional model similar to Model 1 can be used.

5.1.4. Model No. 4. The Complex Four-Dimensional Mode

To introduce a fourth dimension (for example, the difficulty of fulfilling the requirement by the company developing the product, denoted as E_m, which can be evaluated on the interval [0, 1]), one of the solutions is to use quaternions:

$$\mathrm{H} = \mathrm{a} \cdot 1 + \mathrm{b} \cdot \mathrm{i} + \mathrm{c} \cdot \mathrm{j} + \mathrm{d} \cdot \mathrm{k} \quad (5.20)$$

Where*a*, *b*,*c*, *d* ∈ R and *i*, *j* and *k* are imaginary units satisfying the relation $i^2 = j^2 = k^2 = ijk = -1$ and the multiplication properties shown in Table 5.3. This model can also be applied in both static and dynamic variants.

5.2. DIRECT MATHEMATICAL MODELS BASED ON THE CLASSIC KANO MODEL

To overcome the disadvantages highlighted in subchapter 5.1, an adaptation of the basic Kano model is proposed. Specifically, the degree of fulfillment of each feature/requirement is evaluated on a scale from [-1, 1], where *-1* corresponds to 0% fulfillment, *0* corresponds to 50% fulfillment, and *1* corresponds to 100% fulfillment, with an infinite number of intermediate values within the interval [-1, 1]. Similarly, for the level of customer satisfaction, the same scale is proposed: *-1* for disappointed (totally unsatisfied), *0* for indifference, and *1* for delighted (totally satisfied), also with an infinite number of intermediate values in [-1, 1].

Using the concept of the stable part, (iso)morphisms can be designed between requirements and features/specifications, which allow for an evolutionary correlation between them. Although these are not always possible, they remain a goal and an ideal target for product simplification, which can be evaluated by minimizing the number of reference points needed to satisfy a product function or by minimizing the number of design features that respond to a customer requirement.

CHAPTER 6. CONCEPTUAL DESIGN OF THE METHODOLOGY FOR DEVELOPING CO-CREATED PRODUCTS

6.1. BASIC PRINCIPLES AND STAGES OF THE CO-CREATED PRODUCTS DEVELOPMENT METHODOLOGY

6.1.1. Basic principles regarding the methodology for developing co-created products

The methodology for developing co-created products was elaborated in two major stages: preliminary conceptual design and detailed design. The proposed methodology for developing co-created products is based on several essential principles: maximizing the involvement of the client/consumer in the product development process; synthesizing the requirements of all stakeholders; involving three major categories of actors in the co-creation process - the development team, a small group of experts, and a larger group of clients/consumers; establishing/developing appropriate tools to ensure effective collaboration among these three groups; classifying products according to the possible level of co-creation and flexibilizing the methodology for different product categories (see Table 6.1), and validating the methodology and/or some of its stages through case studies.

6.1.2. Stages of the co-created product development methodology

The study proposes a methodology that integrates contributions from clients and other stakeholders into the design process. It consists of five stages: competitive co-design, functional co-design, conceptual co-design, architectural co-design and detailed co-design (see Fig. 6.2)

Table 6.1. Analysis of the Seven Product Classes

Category	Name	Description and examples	Type of production	The level of involvement of potential clients
Category 1	Complex factory-type products	This class includes factory-type products from all fields, including mechanical processing, which contain one or more production units.	Unique; Turnkey factories	The client/beneficiary can collaborate in the project implementation.
Category 2	Complex products such as production units (manufacturing systems)	This class includes products such as production units, workshops, flexible cells, etc.	Unique; Turnkey production units	The client/beneficiary can collaborate in the project implementation; flexibility provided by the possibility to choose from multiple categories.
Category 3	Complex equipment-type products	This class includes complex equipment-type products made to order: systems for processing by combined methods, water jet cutting, modular CNC machines, etc.	Unique/small batch	The client/beneficiary can select modules.
Category 4	Relatively simple industrial equipment and devices	This class includes relatively simple industrial equipment and devices.	Small/medium batch	The client/beneficiary can be involved in all stages of development.
Category 5	Relatively complex mass-market or niche products	This class includes relatively complex mass-market products such as refrigerators, washing machines, automobiles, vacuum cleaners, air conditioning systems, etc.	Medium/large batch	The client/beneficiary can be involved in all stages of development by applying the tools developed in this work.
Category 6	Simple mass-market or niche products	This class includes a wide range of simple mass-market products such as basic household items for kitchen, garden, parks, indoor or ambient furniture, etc.	Large/mass production batch	The client/beneficiary can be involved in all stages of development by applying the tools developed in this work.
Category 7	Service-type products	This class includes all categories of services.	Large/mass production batch	The client/beneficiary can be involved in all stages of development by applying the

				tools developed in this work, some of which are specific to service-type products.

6.2.DEVELOPMENT OF MODELS AND CONCEPTS REGARDING CO-CREATED PRODUCTS

In relation to the existing models in the specialized literature (Bujor, 2019; O'Hern and Rindfleisch, 2008), considering the critical aspects highlighted in the analysis of the current state, as well as the seven product classes defined in subchapter 6.1, we propose the following six categories of concepts associated with co-created products that can be included in a model, defined by the author as the **Model of the 6 COs** (Fig. 6.3): **CO**-realization, **CO**-llaboration, **CO**-improvement (**CO**-modification), **CO**-design (including the five types presented in 6.1.2 – A, B, C, D, E, F), **CO**-mmunication, and **CO**-development.

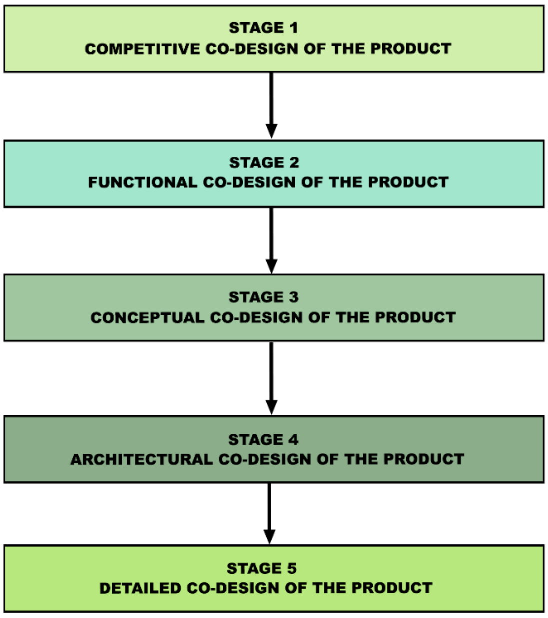


Fig.6.2. The stages of the methodology for developing co-created products and products with personality

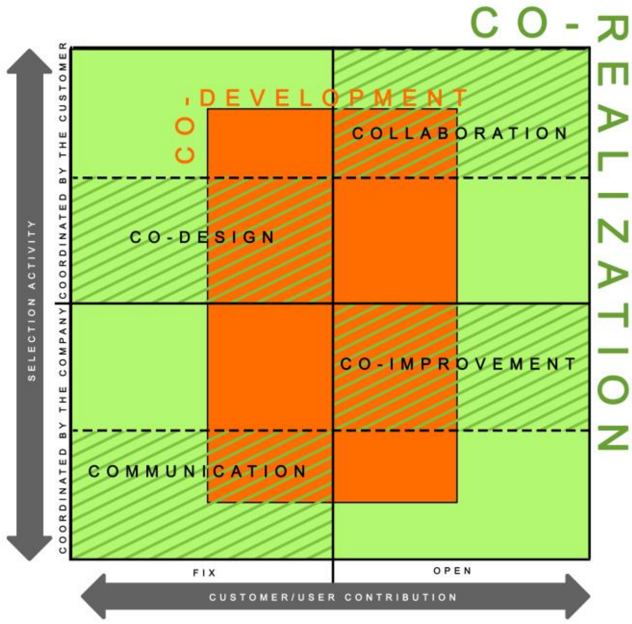


Fig. 6.3. The Model of the 6 COs

We define *co-realization* as the process in which a single client collaborates directly with the supplier to design and produce a complex, unique product, up to its final installation and commissioning at the beneficiary's site. For the concept of collaboration, we adopt the definition from the specialized literature (O'Hern and Rindfleisch, 2008) for the term "collaborating": collaboration is defined as *"the process by which customers have the collective power to develop and improve key components and the structure of new products"* (O'Hern and Rindfleisch, 2008). For the concept of co-improvement (co-modification), we take the definition of the term *Tinkering* (O'Hern and Rindfleisch, 2008): a process in which customers make modifications to a commercially available product, some of which are adopted by the company and incorporated into future product versions. Co-design is the process through which customers contribute directly to product development, either by proposing ideas or by selecting final solutions. Based on the classical design stages (Vișan and Ionescu, 2006), four main forms of co-design are identified:

A. Competitive co-design – customers participate in defining product specifications, considering the entire product lifecycle;

B. Functional co-design – the product's functions are designed together with users, establishing functional hierarchies (general, primary, secondary functions, etc.) and phenomena associated with each, using multicriteria analyses;

C. Conceptual co-design – customers contribute to generating and selecting concepts through creative methods such as QFD, TRIZ, or systems evolution analysis, focusing on identifying the optimal concept;

D. Architectural co-design – involves preliminary product structuring and defining subsystems.

For the concept of **communication**, we adopt the definition given by O'Hern and Rindfleisch for the term “Submitting”: communication can be defined as the process through which customers directly submit new product ideas to the company in a form established by the company that will develop the product (O'Hern and Rindfleisch, 2008). Finally, we define co-development as a complex process in which customers actively participate in all phases of product development, from market research to the launch of mass production.

6.3. THE STEPS OF THE FIVE COMPONENT STAGES OF THE METHODOLOGY

As mentioned in the previous subchapter, the methodology developed by the author consists of five stages, each of which is composed of specific steps that play a role in organizing and structuring this methodology, as well as in the efficient sequencing of the processes necessary for product development. The extended structure of the methodology, highlighting both the stages and the steps, is presented in Figure 6.5.

Stages and steps of the methodology	CLASS 1 Complex factory-type products			CLASS 2 Complex production section products (Manufacturing systems)			CLASS 3 Complex equipment-type products			CLASS 4 Simple equipment and devices			CLASS 5 Complex mass-market or niche products			CLASS 6 Simple mass-market or niche products			CLASS 7 Service-type products		
Actors: D – Development team; A – Expert group; B – Consumer group	**D**	**A**	**B**	**D**	**A**	**B**	**D**	**A**	**B**	**D**	**A**	**B**	**D**	**A**	**B**	**D**	**A**	**B**	**D**	**A**	**B**
STAGE 1. COMPETITIVE CO-DESIGN OF THE PRODUCT																					
1.1. Identifying the need, the potential product (PP), and the generalized potential product (GPP)	X			X			X			X			X			X			X		
1.1.1. Establishing the general need (G.N.)	x			x			x			x			x			x			x		
1.1.2. Opportunity analysis	x			x			x			x			x			x			x		
1.1.3. Defining the potential product (PP)	x			x			x			x			x			x			x		
1.1.4. Defining the generalized potential product (GPP) A. Defining the general need for GPP (G.N.-GPP) B. Framing the general need C. Type and source of G.N.-GPP D. Classification and definition of GPP E. Systemic analysis of GPP F. State analysis of GPP G. Interaction with the user H. GPP supra-system	x			x			x			x			x			x			x		
1.1.5. Formulating the mission for the developed product	x			x			x			x			x			x			x		
1.2. Co-defining the market requirements	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
1.2.1. Identifying potential stakeholders	x			x			x			x			x			x			x		
1.2.2. Collecting the voice of the customer – establishing requirements	x			x			x			x			x			x			x		
1.2.3. Determining the relative importance of requirements (Application #1)		x			x			x			x			x	x		x	x		x	x
1.3. Co-defining target values and acceptable limit values, and classifying characteristics	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
1.3.1. Study of competing products	x			x			x			x			x			x			x		
1.3.2. Co-defining the correlations between requirements and specifications/characteristics (Application #2)		x			x			x			x			x	x		x	x		x	x
1.3.3. Co-defining target values and acceptable limit values (Application #3)	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	x
1.3.4. Classifying characteristics according to the KANO model	x	x		x	x		x	x		x	x		x		x	x		x	x		x
1.3.5. Mathematical modeling of the dependency between requirements and characteristics/specifications A. Establishing dependency functions between requirements and characteristics/specifications B. Establishing possible (iso)morphisms between the set of requirements and the set of characteristics C. Modeling using the KANO and IF-KANO models	x			x			x			x			x			x			x		
STAGE 2. FUNCTIONAL CO-DESIGN OF THE PRODUCT																					
2.1. Establishing the mode of operation of the product	X			X			X			X			X			X			X		
2.2. Determining the functional implications of the requirements	X			X			X			X			X			X			X		
2.3. Defining the general function and main categories of functions (Application #4)	X			X			X			X			X			X			X		
2.4. Functional modeling	X			X			X			X			X			X			X		
2.5. Ordering and prioritizing functions based on their utility values (Application #5)		X			X			X			X			X	X		X	X		X	X
2.6. Identifying the phenomena through which the functions can be fulfilled	X			X			X			X			X			X			X		
STAGE 3. CONCEPTUAL CO-DESIGN OF THE PRODUCT																					
3.1. Co-generation of partial and complete concepts	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
3.1.1. Co-generation of concepts using the synergy of TRIZ-QFD-Taguchi A. Problem description B. Completing the sections of the House of Quality C. Identifying contradictions in the House of Quality roof according to TRIZ philosophy D. Formulating contradictions E. Establishing generic and specific conceptual solutions using the Contradiction Matrix, the 39 Parameters, and the 40 Inventive Principles (SCS) (Application #6)	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	x

3.1.2. Co-generation of concepts using the Nine Screens Method (Application #7)	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	x
3.1.3. Co-generation of concepts using classical ideality indicators A. The ideal product B. Calculation of the ideality indicator		x			x			x			x			x	x		x	x		x	x
3.1.4. Co-generation of concepts using CREAX indicators (Application #8)	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	x
3.1.5. Co-generation of concepts using the laws of technical system evolution (Application #9)	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	x
3.1.6. Generating concepts using physical contradictions	x			x			x			x			x			x			x		
3.1.7. Generating concepts using Su-Field Analysis	x			x			x			x			x			x			x		
3.1.8. Generating concepts using generalization, analogy, and extrapolation	x			x			x			x			x			x			x		
3.2. Defining partial concepts	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
3.2.1. Defining partial concepts	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	x
3.2.2. Morphological analysis of partial concepts and establishing the nomenclature of complete concepts	x	x		x	x		x	x		x	x		x	x	x	x	x	x	x	x	
3.3. Sorting concepts (Application #10)		X			X			X			X	X		X	X		X	X		X	X
3.4. Selecting the optimal concept (AHP) (Application #11)		X			X			X			X	X		X	X		X	X		X	X
STAGE 4. ARCHITECTURAL CO-DESIGN OF THE PRODUCT																					
4.1. Creating the product's schematic (block) model	X	X		X	X		X	X		X	X		X		X	X		X	X		X
4.2. Co-defining the product's subsystems	X	X		X	X		X	X		X	X		X		X	X		X	X		X
4.2.1. Defining modules	x			x			x			x			x			x			x		
4.2.2. Determining the degree of modularity *Gm*	x			x			x			x			x			x			x		
4.2.3. Identifying (sub)assemblies to be supplied (provided, purchased), standardized	x			x			x			x			x			x			x		
4.2.4. Co-defining the main subsystems (Application #12)	x	x		x	x		x	x		x	x		x		x	x		x	x		x
4.2.5. Determining the degree of modular simplicity *Gsm*, standardization *Gss* and supply *Gsa*	x			x			x			x			x			x			x		
4.2.6. Proposals for simplification, unification, standardization, normalization	x			x			x			x			x			x			x		
4.2.7. Defining consumable elements	x			x			x			x			x			x			x		
4.2.8. Defining elements subject to normal wear	x			x			x			x			x			x			x		
4.2.9. Determining the degree of flexibility	x			x			x			x			x			x			x		
4.2.10. Determining the degree of reconditioning, reuse, remanufacturing	x			x			x			x			x			x			x		
4.2.11. Determining the degree of adaptation	x			x			x			x			x			x			x		
4.3. Co-defining the topology of subsystems/modules/subassemblies (Application #13)	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
4.4. Defining interactions (positive, negative, insufficient)	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
4.5. Co-defining the degree of differentiation for different product variants – combinations of modules (alternative modules, extra options) (Application #14)	X	X		X	X		X	X		X	X		X	X	X	X	X	X	X	X	X
4.6. Defining implications regarding manufacturing costs	X			X			X			X			X			X			X		
4.7. Establishing the final architecture(s) of the product	X			X			X			X			X			X			X		
STAGE 5. DETAILED CO-DESIGN OF THE PRODUCT																					
5.1. Prescribed precision sizing	X			X			X			X			X			X			X		
5.2. Product ergonomics (Application #15)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5.3. Industrial design engineering (Application #16)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5.4. Establishing materials	X			X			X			X			X			X			X		
5.5. Verification of operating simulation requests	X			X			X			X			X			X			X		
5.6. Developing assembly drawings and execution drawings	X			X			X			X			X			X			X		

Fig. 6.5. Detailed breakdown of the stages and steps of the co-created product development methodology

CHAPTER 7. CONTRIBUTIONS REGARDING THE DEVELOPMENT OF METHODS, TECHNIQUES, AND TOOLS FOR THE CREATION OF CO-CREATED PRODUCTS AND PRODUCTS WITH PERSONALITY

7.1. METHODS, TECHNIQUES, AND TOOLS APPLICABLE IN THE COMPETITIVE CO-DESIGN STAGE

Competitive co-design involves the active participation of clients in defining the product's characteristics and specifications, taking into account its entire life cycle. This approach is based on integrating the "voice of the customer" into the design process, according to user-centered design principles.

7.1.1. Collecting the voice of the customer

To ensure the product's relevance, both active and passive methods of collecting customer requirements are used. Passive methods include analyzing existing data — complaints, feedback, industry information — while active methods involve direct interactions with customers, such as interviews, focus groups, and surveys. The purpose of these methods is to accurately identify customers' requirements, expectations, and preferences to support the design of market-adapted products.

7.1.2. Methods, techniques, and tools for co-determining the importance of product requirements and specifications

In the context of competitive design, co-determining the relative importance of requirements, target values, and acceptable limit values involves the active participation of customers. The author proposes three digital tools designed to facilitate this co-creation process, the first of which is dedicated to prioritizing requirements.

Tool/Application #1: Co-determining the Importance of Requirements

After collecting and processing customer requirements, these are grouped into primary requirements, each assigned an importance score on a numerical scale (1–5 or 1–10). Traditionally, prioritization is done by the development team. The new methodology proposes involving customers (Group B) and experts (Group A), depending on the product class, through an application that calculates the average scores assigned to each requirement.

This application, initially developed in LabView and later in an interactive web version (Fig. 7.6), allows the input of importance scores and automatic updating of averages. Its applicability was demonstrated through a case study on a Natural **System for Climate Control and Light Filtration (SNCFL)** — a modular, decorative, and sustainable product that combines self-irrigation, air purification, and light filtration functions. The evaluation of requirements involved 10 experts and 30 users, and the final importance of each requirement was calculated as a weighted average (60% Group A, 40% Group B). The most important requirements identified were air purification, light filtration, and the beneficial effect on well-being.

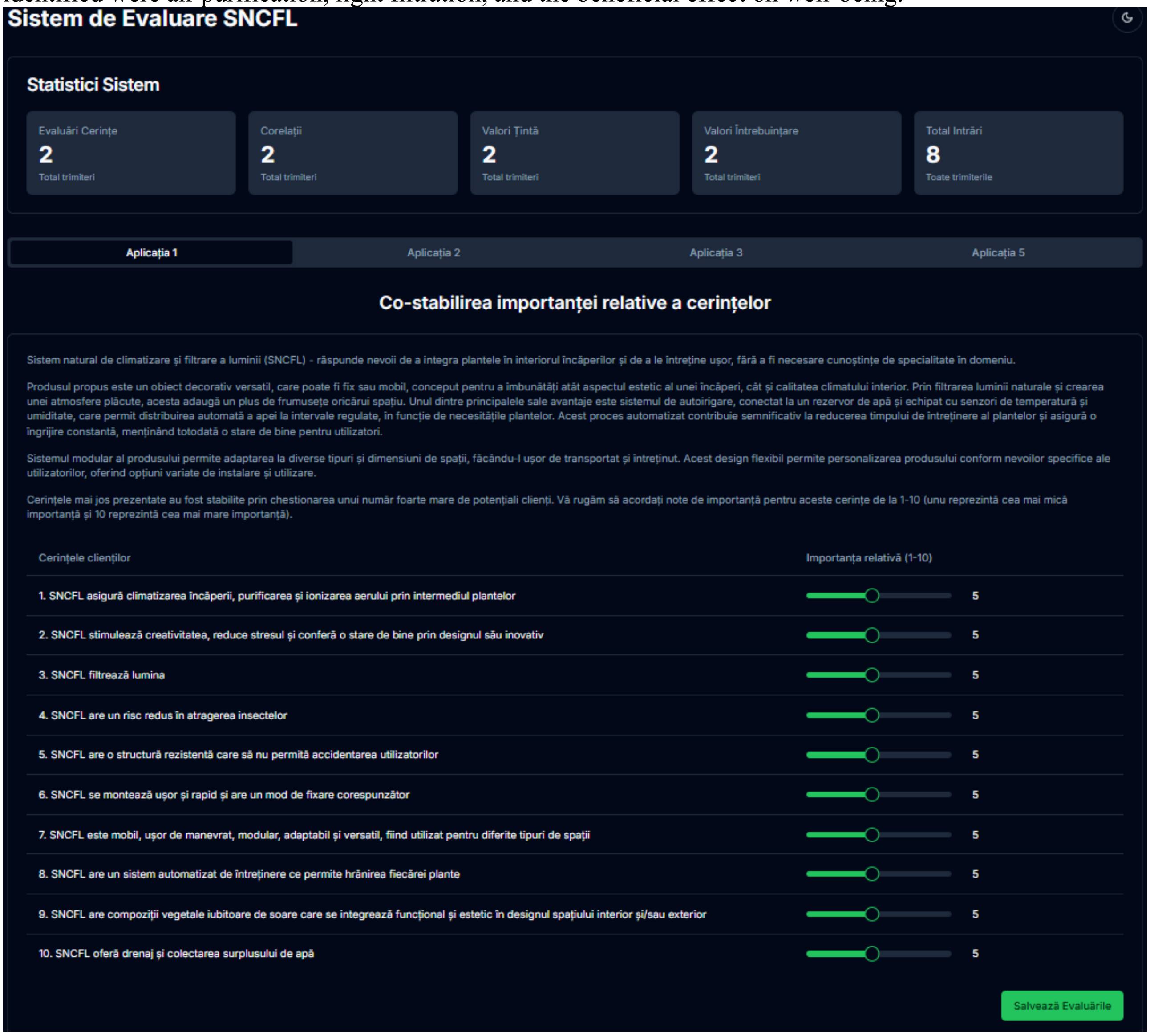


Fig. 7.6. Interactive Application #1 for Inputting the Relative Importance

Tool/Application #2: Co-Determining the Correlation Between Requirements and Characteristics

Application #2 is designed to be used in stage 1.3.2, which addresses the co-determination of correlations between customer requirements and product characteristics/specifications (figs. 7.9, 7.14, 7.15). This tool enables the evaluation of the relationship between customer requirements and the technical specifications of the product. Unlike classical methods (matrices or Quality Function Deployment – QFD House of Quality), it proposes using a scale from 0 to 10 to quantify the intensity of correlations. The associated application collects scores from participants (experts and/or customers) and calculates average scores, which can then be converted into a simplified scale (1-3-9), specific to the QFD method.

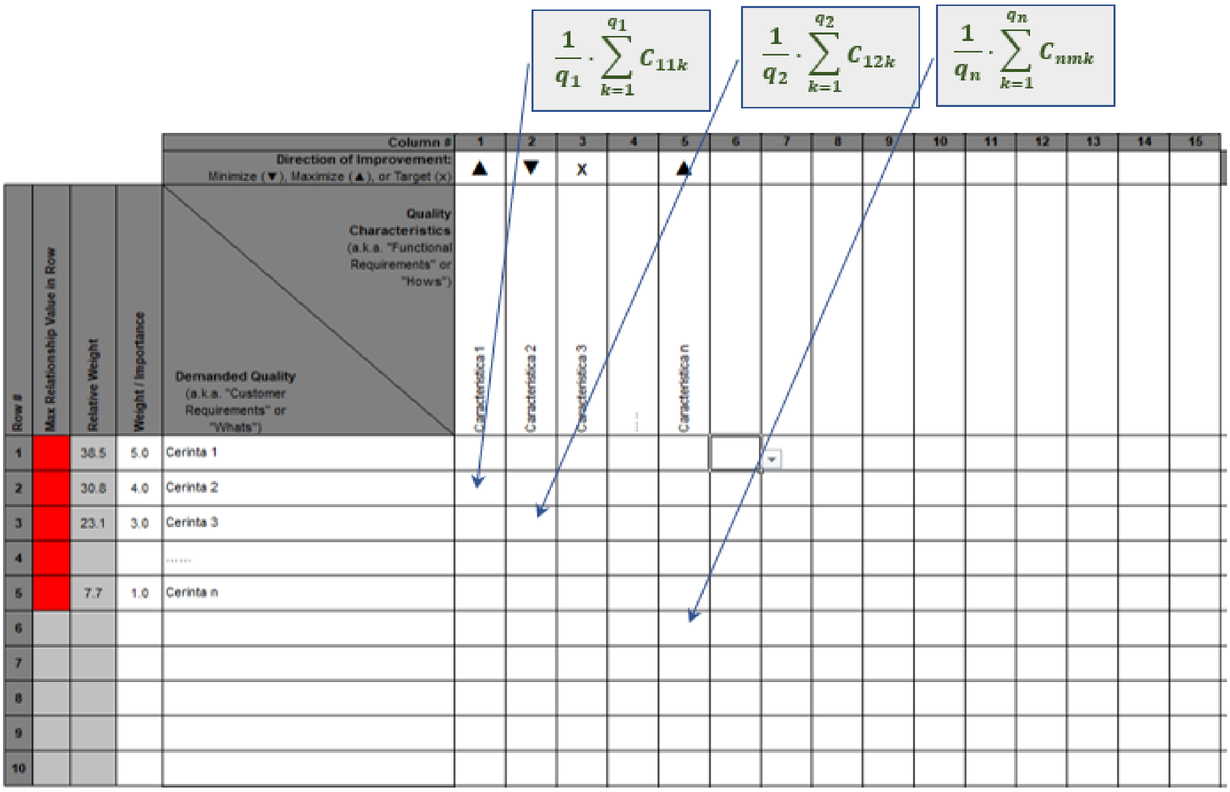


Fig. 7.9. Adaptation of QFD for Co-Determining the Correlation Between Requirements and Characteristics

Using Application #2, scores from 0 to 10 were assigned to establish correlations between each requirement and each characteristic. These scores were then mapped onto the 1-3-9 scale in the central area of the House of Quality, as presented in Figure 7.12.

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▲	▲	▲	▼	▼	▲	▲	▼	▼	x			
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Total surface area covered by a module	Number of watering/fertilizing cycles per day	Number of modules	Number of plants per module	Number of plant species	Weight of a module	Volume of a module	Active surface area of a module	Inflorescence	Maintenance time	Power consumption	Liquid flow			
1	9	12.7	9.6	Ensures room air conditioning, air purification, and ionization through the use of plants.	Θ	O	Θ	Θ	Θ	▲	▲	Θ	Θ	▲	▲	O			
2	9	11.2	8.5	Stimulates creativity, reduces stress, and promotes a sense of well-being.	O	▲	▲	Θ	Θ	▲	▲	O	Θ	O	▲	O			
3	9	12.2	9.2	Filters light.	Θ	▲	Θ	Θ	Θ	▲	▲	Θ	Θ	▲	▲	▲			
4	9	7.3	5.5	It has a low risk of attracting insects.	O	▲	O	Θ	Θ	▲	O	▲	Θ	▲	▲	O			
5	3	9.7	7.3	It has a sturdy structure that prevents user injury.	▲	▲	O	▲	▲	O	O	▲	▲	O	O	▲			
6	9	10.4	7.9	It is easy and quick to install and has a proper fastening method.	O	▲	Θ	O	O	Θ	Θ	O	▲	O	▲	▲			
7	9	8.5	6.4	It is mobile, easy to handle, modular, adaptable, and versatile for different types of spaces.	Θ	O	Θ	O	O	Θ	Θ	O	▲	▲	O	▲			
8	9	10.4	7.9	It has an automated maintenance system that allows each plant to be nourished.	▲	O	O	O	O	▲	▲	Θ	Θ	Θ	O	Θ			
9	9	10.1	7.6	It features plant compositions that integrate both functionally and aesthetically into indoor and outdoor spaces.	▲	▲	O	O	O	▲	▲	Θ	Θ	O	O	Θ			
10	9	7.5	5.7	It provides drainage and collects excess water.	O	Θ	Θ	Θ	Θ	O	O	Θ	Θ	Θ	Θ	Θ			

Fig. 7.12. The central part of the quality house used for co-determining correlations between requirements and characteristics: Θ - strong correlation(9), O - medium correlation(3), ▲ - weak correlation(1)

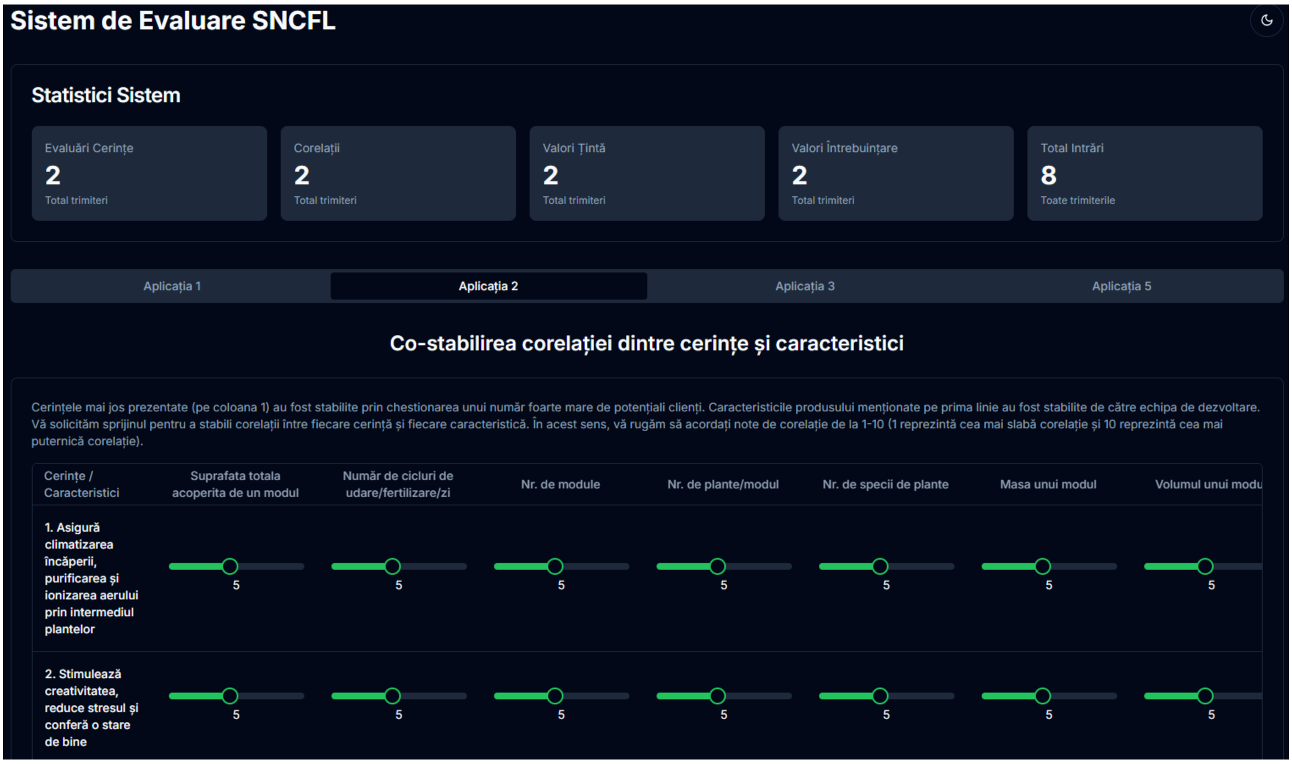


Fig. 7.14. Interactive Application #2 for completing correlations

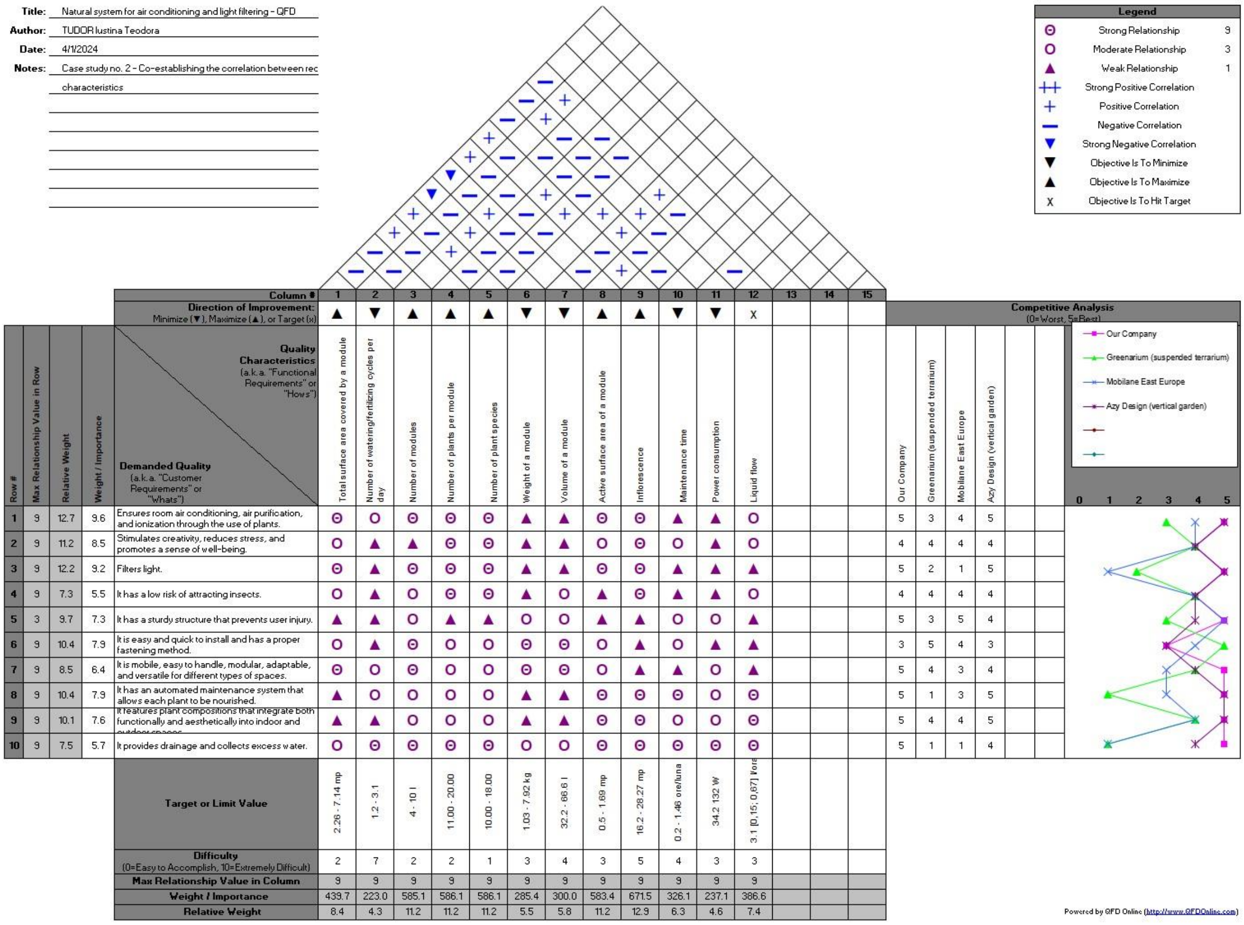


Fig. 7.15. Complete House of Quality for the product *Natural Climate Control and Light Filtering System*

C. Instrument/Application #3: Co-determination of Target Values and Acceptable Limit Values of Characteristics

To establish target values, two strategies are commonly used — the classification of product characteristics developed by Genichi Taguchi and setting target values by benchmarking against the best competitor values. This work proposes a third strategy (Table 7.6), applicable for co-created products, based on the average values provided by potential customers (Group B) and/or a group of experts (Group A).

Table 7.6. Definition of Specification Categories

Strategy		Target values	Acceptable limit values
Strategy #1: Taguchi Classification	GTB	Infinite	-
	STB	0	-
	NTB	N	[N - LLD_L, N + ULD_L] (LLD – lower limit deviation, ULD – upper limit deviation)
Strategy #2: Best Competitive Value	GTB	The highest value of competing products	The average of the maximum values of competing products
	STB	The lowest value of competing products	The average of the minimum values of competing products
	NTB	The average of the nominal values of competing products, Nm	[N_m - LLD_L, N_m + ULD_L]
Strategy #3: Co-created Products: the average of	GTB	The average of the maximum values given by groups A and/or B	The average of the acceptable minimum values given by groups A and/or B

customer-assigned values	STB	The average of the minimum values given by groups A and/or B	The average of the acceptable maximum values given by groups A and/or B
	NTB	The average of the nominal values given by groups A and/or B, N_c, and deviations resulting from the average of the values given by groups A and/or B	Deviations [Nc - LLDc, Nc + ULDc]

Figure 7.20 presents the interactive form of this application, hosted on a server, where members of groups A and/or B can enter values. The product characteristics are grouped into three categories: NTB, STB, and GTB.

Fig. 7.20. Interactive Application #3 for NTB-type Values

Tables 7.8 and 7.9 present the results obtained from a case study developed within the thesis for the product Natural Climate Control and Light Filtering System.

Table 7.8. Target (ideal) values and acceptable limits

No. Chars.	*Nr. of associated requirement C_a**	*Characteristic*	*Type of characteristic according to Taguchi*	*Relative importance of the characteristic**	*UM*	*Minimum limit value*			*Target value (Ideal value)*			*Maximum limit value*		
						m_A	m_B	m	m_A	m_B	m	m_A	m_B	m
1.	1- 4, 6, 7, 10	Ch_1. Total area covered by a module	GTB	8.4	m^2	2.35	2.12	**2.26**	6.40	8,26	**7.14**			
2.	1, 7, 8, 10	Ch_2. Number of watering/fertilizing cycles per day	STB	4.3	-				1.10	1.34	**1.2**	3	3,21	**3.1**
3.	1, 3-10	Ch_3. Number of modules	GTB	11.2	-	4.10	4.9	**4.42 (4)**	8.60	10.85	**9.5 (10)**			
4.	1-4, 6-10	Ch_4. Number of plants per module	GTB	11.2	-	11.50	10,2	**10.98 (11)**	19.20	19.95	**19.5 (20)**			
5.	1-4, 6-10	Ch_5. Number of plant species	GTB	11.2	-	9.20	9.8	**9.44 (10)**	16.20	20.4	**17.88 (18)**			
6.	5, 6, 7, 10	Ch_6. Mass of a module	STB	5.5	kg				0.93	1,2	**1.03**	8	7.8	**7.92**
7.	4-7, 10	Ch_7. Volume of a module	STB	5.8	1				33	31	**32.2**	65	69	**66.6**

8.	1-3, 6-10	Ch_8. Active surface area of a module	GTB	11.2	m^2	0.46	0.55	**0.50**	1.41	2.1	**1.69**			
9.	104, 8-10	Ch_9. Inflorescence	GTB	12.9	m^2	17.50	14.26	**16.2**	28.00	28.67	**28.27**			
10.	2, 5, 6, 8, 9, 10	Ch_{10}. Maintenance time	STB	6.3	Hours/month				0.20	0.22	**0.2**	1.40	1.56	**1.46**
11.	5, 7-10	Ch_{11}. Power consumption	STB	4.6	W				37	30	**34.2**	120	150	**132**
12.	1, 2, 4, 8, 9, 10	Ch_{12}. Liquid flow rate	NTB	7.4	l/hour	0.17	0.12	**0.15**	0.37	0.22	**0.31**	0.82	0.44	**0.67**

*According to the House of Quality, considering only correlations rated 3 and 9;
** From the footer of the House of Quality

Table 7.9. Target (ideal) values and acceptable limits grouped according to Kano's model

No. Chars	*Type of characteristic according to Kano*	*Associated requirement number C_a*	*Characteristic*	Type of characteristic according to Taguchi	Relative importance of the characteristic	*Unit of measurement*	*Minimum limit value*	*Target value (Ideal value)*	*Maximum limit value*
1.	Basic characteristics (expected, "must be")	1- 4, 6, 7, 10	Ch_1. Total area covered by a module	GTB	8.4	m^2	**2.26**	**7.14**	
5.		1-4, 6-10	Ch_5. Number of plant species	GTB	11.2	-	**10**	**18**	
3.	Performance characteristics (desired, "one dimension")	1, 3-10	Ch_3. Number of modules	GTB	11.2	-	**4**	**10**	
4.		1-4, 6-10	Ch_4. Number of plants per module	GTB	11.2	-	**11**	**20**	
6.		5, 6, 7, 10	Ch_6. Mass of a module	STB	5.5	kg		**1.03**	**7.92**
7.		4-7, 10	Ch_7. Volume of a module	STB	5.8	l		**32.2**	**66.6**
8.		1-3, 6-10	Ch_8. Active surface area of a module	GTB	11.2	m^2	**0.5**	**1.69**	
10.		2, 5, 6, 8, 9, 10	Ch_{10}. Maintenance time	STB	6.3	Hours/month		**0.2**	**1.46**
11.		5, 7-10	Ch_{11}. Power consumption	STB	4.6	W		**34.2**	**132**
12.		1, 2, 4, 8, 9, 10	Ch_{12}. Liquid flow rate	NTB	7.4	l/ hour	**0.31**	**0,2**	**0,67**
2.	Delightful characteristics		Ch_2. Number of watering/fertilizing cycles per day	STB		-		**1.2**	**3.1**
9.			Ch_9. Inflorescence	GTB		m^2	**16.2**	**28.7**	

7.2. METHODS, TECHNIQUES AND TOOLS APPLICABLE IN THE FUNCTIONAL CO-DESIGN STAGE

Functional co-design is the stage in the design process where, through collaboration between specialists and potential customers, the product's functions are defined based on specifications and functional requirements. This includes identifying the general function, main and secondary functions, critical functions, and the fundamental phenomena needed to achieve them. The law of evolution toward ideality is applied, asking customers to propose new functions or identify unnecessary ones.

For the functional co-design stage, two applications have been developed: Application #4 (in step 2.3) and Application #5 (in step 2.5), along with Application #8, created for the conceptual co-design stage, which uses indicators of evolution toward ideality (see subchapter 5.5). **Application #4** is used by the development team to formulate and classify functions according to definitions from the literature.

Application #5 is designed to co-establish the hierarchy of functions based on their usage value, evaluated by experts and potential customers. The weighted average of importance scores (from 1 to 10) given by two distinct groups (experts – Group A and customers – Group B) is calculated. Figure 7.24 shows the interactive form of Application #5, where members of Groups A and B can assign values from 1 to 10 for each function. Table 7.11 presents the results obtained by applying this tool.

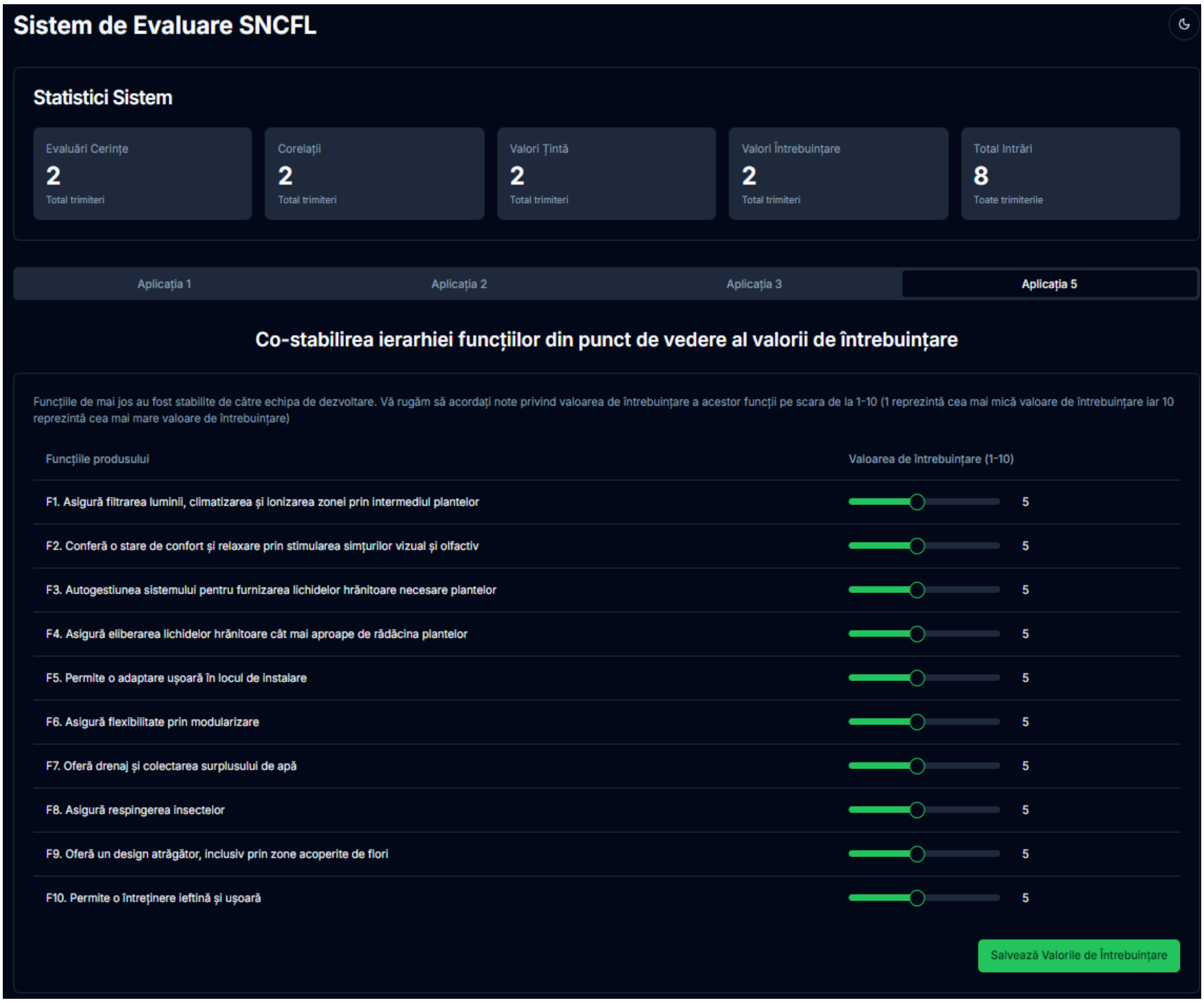


Fig. 7.24. Interactive Application #5 for determining the usage value of each function

Table 7.11. Ranking of functions based on their usage value

Function No.	*Function description*	*Usage value, v_A*	*Usage value, v_B*	*Composite usage value $v_C = 0,2\ v_A + 0,8\ v_B$*	*Weight in usage value x [%]*
F1.	*Ensures light filtering, climate control, and ionization of the area through plants*	9.40	9.80	9.72	13.18
F2.	*Provides comfort and relaxation by stimulating visual and olfactory senses*	9.70	9.80	9.78	13.26
F3.	*Self-management of the system to supply the nutrient liquids required by the plants*	8.20	8.33	8.30	11.26
F4.	*Ensures the release of nutrient liquids as close as possible to the plant roots*	7.30	7.16	7.19	9.75
F5.	*Allows easy adaptation to the installation site*	6.30	6.86	6.75	9.15

F6.	*Provides flexibility through modularization*	6.30	6.16	6.19	8.39
F7.	*Provides drainage and collection of excess water*	4.60	4.67	4.66	6.31
F8.	*Ensures insect repellent*	5.90	6.33	6.24	8.47
F9.	*Offers an attractive design, including areas covered with flowers*	6.70	7.67	7.48	10.14
F10.	*Allows cheap and easy maintenance*	5.80	7.86	7.45	10.10

7.3. METHODS, TECHNIQUES, AND TOOLS APPLICABLE IN THE CONCEPTUAL CO-DESIGN STAGE

Conceptual co-design is an important stage in product development that involves generating a large number of concepts, either individually or in groups, to identify the optimal solution. The literature offers both qualitative and quantitative methods to stimulate creativity, and for involving customers - methods such as QFD, the Nine Screens Method, the Eight Laws of System Evolution and the 40 Inventive Principles of TRIZ have been analyzed. In this context, six applications were developed for co-creating concepts:

- Application #6: Co-establishing conceptual solutions using the Contradiction Matrix, 39 parameters, and the 40 inventive principles;
- Application #7: Co-generating concepts through the Nine Screens Method;
- Application #8: Co-generating concepts using CREAX indicators;
- Application #9: Co-generating concepts based on the laws of technical system evolution;
- Application #10: Concept sorting;
- Application #11: Selecting the optimal concept.

A. Tool/Application #6. Co-establishing Generic (GCS) and Specific Conceptual Solutions (SCS) using the Contradiction Matrix, the 39 Parameters, and the 40 Inventive Principles

Using the 39 parameters, Altshuler's 40 inventive principles (Altshuler, 1997; Cavalluchi, 2001), and the contradiction matrix, based on a model created by the author (involving groups A, B, and D), four contradictions were formulated, taken from the roof of the House of Quality (Fig. 7.15) as presented in Table 7.13, for the SNCFL case study. Using the CREAX software, the inventive principles were identified, based on which 24 concepts were formulated by groups A and B. From these, the development team selected 18 concepts for the SNCFL case study.

Table 7.13. Formulation of Technical Contradictions (Adapted from Ionescu, 2018 for the SNCFL Product Case)

No.	Characteristic/parameter to be improved			Characteristic/parameter that worsens				Inventive principles
	Name of the characteristic (parameter)	**Desired improvement direction / Taguchi category**	**Equivalent TRIZ parameter (P1…P39)**	**Name of the characteristic (parameter)**	**Desired improvement direction / Taguchi category**	**Undesired effect**	**Equivalent TRIZ parameter (P1…P39)**	
1	Total area covered by a module	▲ GTB	P6. Total area covered by a module	Number of modules	▲ GTB	Decreases	P36. Device complexity	1, 18, 36
	C1. When the total area covered by a module (P6) is improved/increased, the number of modules parameter (P36) worsens/decreases.							
2	Total surface area covered by a module	▲ GTB	P6. Area of stationary object	Number of watering cycles	▼ STB	Increases	P26. Quantity of substance	2, 18, 40, 4
	C2. When the total area covered by a module (P6) is improved/increased, the number of watering cycles (P26) worsens/increases.							
3	Total surface area covered by a module	▲ GTB	P6. Area of stationary object	Mass of a module	▼ STB	Increases	P2. Weight of stationary object	30, 2 14, 18
	C3. When the total area covered by a module (P6) is improved/increased, the mass of a module (P2) worsens/increases.							
4	Power consumption	▼ STB	P22. Loss of energy	Liquid flow rate	**X** NTB	Deviations from the nominal value	P23. Loss of substance	35, 27, 2, 37

	C4. When power consumption (P22) is improved/decreased, the liquid flow rate parameter (P23) worsens (deviates from the target value).

B. Tool/Application #7. Co-generation of Concepts Using the Nine-Screens Method

For the purpose of this work, Figure 7.28 presents an adaptation of the Nine-Screens method for studying the evolution of customer requirements and, respectively, the evolution of product characteristics/specifications. Forecasting their future evolution can be used in gathering the voice of the customer, discovering latent needs or designing new attractive features according to Kano's model.

Figure 7.28. The Nine-Screens Method Applied to the Study of Requirements and Characteristics

•		Distant past	Mid-term past	Recent past	Present	Near future	Distant future
Laws of transition from system to supra-system, respectively to sub-system	Supra-system	• **Customer requirements** in the distant past, at the supra-system level: $C_{S1}(t_i)$, $C_{S2}(t_i)$,…, $C_{Sn}(t_i)$ • **Product** characteristics in the distant past, at the supra-system level: $Ch_{S1}(t_i)$, $Ch_{S2}(t_i)$,…, $Ch_{Sm}(t_i)$	• **Customer requirements** in the mid-term past, at the supra-system level $C_{S1}(t_m)$, $C_{S2}(t_m)$,…, $C_{Sn}(t_m)$ • **Product characteristics in** the mid-term past, at the supra-system level $Ch_{S1}(t_m)$, $Ch_{S2}(t_m)$,…, $Ch_{Sm}(t_m)$	• **Customer requirements** in the recent past, at the supra-system level $C_{S1}(t_a)$, $C_{S2}(t_a)$,…, $C_{Sn}(t_a)$ • **Product characteristics** in the recent past, at the supra-system level $Ch_{S1}(t_a)$, $Ch_{S2}(t_a)$,…, $Ch_{Sm}(t_a)$	• Customer requirements in the present, at the supra-system level: $C_{S1}(t_p)$, $C_{S2}(t_p)$,…, $C_{Sn}(t_p)$ • Product characteristics in the present, at the supra-system level: $Ch_{S1}(t_p)$, $Ch_{S2}(t_p)$,…, $Ch_{Sm}(t_p)$	• Customer requirements in the near future, at the supra-system level: $C_{S1}(t_{va})$, $C_{S2}(t_{va})$,…, $C_{Sn}(t_{va})$ • Product characteristics in the near future, at the supra-system level: $Ch_{S1}(t_{va})$, $Ch_{S2}(t_{va})$,…, $Ch_{Sm}(t_{va})$	• Customer requirements in the distant future, at the supra-system level: $C_{S1}(t_{vi})$, $C_{S2}(t_{vi})$,…, $C_{Sn}(t_{vi})$ • Product characteristics in the distant future, at the supra-system level: $Ch_{S1}(t_{vi})$, $Ch_{S2}(t_{vi})$,…, $Ch_{Sm}(t_{vi})$
	System	• **Customer requirements** in the distant past, at the system level: $C_1(t_i)$, $C_2(t_i)$,…, $C_n(t_i)$ • **Product characteristics** in the distant past, at the system level: $Ch_1(t_i)$, $Ch_2(t_i)$,…, $Ch_n(t_i)$	• Customer requirements in the mid-term past, at the system level $C_1(t_m)$, $C_2(t_m)$,…, $C_n(t_m)$ • Product characteristics in the mid-term past, at the system level $Ch_1(t_m)$, $Ch_2(t_m)$,…, $Ch_n(t_m)$	• Customer requirements in the recent past, at the system level $C_1(t_a)$, $C_2(t_a)$,…, $C_n(t_a)$ • Product characteristics in the recent past, at the system level $Ch_1(t_a)$, $Ch_2(t_a)$,…, $Ch_n(t_a)$	• Customer requirements in the present, at the system level: $C_1(t_p)$, $C_2(t_p)$,…, $C_n(t_p)$ • Product characteristics in the present, at the system level: $Ch_1(t_p)$, $Ch_2(t_p)$,…, $Ch_n(t_p)$	• Customer requirements in the near future, at the system level: $C_1(t_{va})$, $C_2(t_{va})$,…, $C_n(t_{va})$ • Product characteristics in the near future, at the system level: $Ch_1(t_{va})$, $Ch_2(t_{va})$,…, $Ch_n(t_{va})$	• Customer requirements in the distant future, at the system level: $C_1(t_{vi})$, $C_2(t_{vi})$,…, $C_n(t_{vi})$ • Product characteristics in the distant future, at the system level: $Ch_1(t_{vi})$, $Ch_2(t_{vi})$,…, $Ch_n(t_{vi})$
	Sub-system	• **Customer requirements** in the distant past, at the sub-system level: $C_{s1}(t_i)$, $C_{s2}(t_i)$,…, $C_{sn}(t_i)$ • **Product characteristics** in the distant past, at the sub-system level: $Ch_{s1}(t_i)$, $Ch_{s2}(t_i)$,…, $Ch_{sn}(t_i)$	• Customer requirements in the mid-term past, at the sub-system level $C_{s1}(t_m)$, $C_{s2}(t_m)$,…, $C_{sn}(t_m)$ • Product characteristics in the mid-term past, at the sub-system level $Ch_{s1}(t_m)$, $Ch_{s2}(t_m)$,…, $Ch_{sm}(t_m)$	• Customer requirements in the recent past, at the sub-system level $C_{s1}(t_a)$, $C_{s2}(t_a)$,…, $C_{sn}(t_a)$ • Product characteristics in the recent past, at the sub-system level $Ch_{s1}(t_a)$, $Ch_{s2}(t_a)$,…, $Ch_{sm}(t_a)$	• Customer requirements in the present, at the sub-system level: $C_{s1}(t_p)$, $C_{s2}(t_p)$,…, $C_{sn}(t_p)$ • Product characteristics in the present, at the sub-system level: $Ch_{s1}(t_p)$, $Ch_{s2}(t_p)$,…, $Ch_{sm}(t_p)$	• Customer requirements in the near future, at the sub-system level: $C_{s1}(t_{va})$, $C_{s2}(t_{va})$,…, $C_{sn}(t_{va})$ • Product characteristics in the near future, at the sub-system level: $Ch_{s1}(t_{va})$, $Ch_{s2}(t_{va})$,…, $Ch_{sm}(t_{va})$	• Customer requirements in the distant future, at the sub-system level: $C_{s1}(t_{vi})$, $C_{s2}(t_{vi})$,…, $C_{sn}(t_{vi})$ • Product characteristics in the distant future, at the sub-system level: $Ch_{s1}(t_{vi})$, $Ch_{s2}(t_{vi})$,…, $Ch_{sm}(t_{vi})$
		Laws of evolution of requirements Laws of evolution of characteristics (of systems)				Forecast based on the laws of evolution of requirements and the laws of evolution of characteristics	

C. Tool/Application #8. Co-generation of Concepts Using CREAX Indicators

Another method for co-generating concepts involves the 28 CREAX indicators (Ionescu et al., 2012). By studying the evolution according to each indicator, a rating from 1 to 10 is given for the current state of the product. Improvement solutions are then proposed to push the evolution one or more steps closer to the ideal, after which the new situation is re-evaluated on a scale from 1 to 10. A comparative analysis can be performed by representing these ratings on a radar chart for both the existing product and the improved product. The difference between applying the CREAX indicators from the specialized literature (Ionescu et al., 2012) and the present application adapted for co-created products is that the ratings for both the current and improved product are assigned jointly with groups A and B.

D. Tool/Application #9. Co-generation of concepts using the 8 laws of evolution of technical systems

The eight laws of evolution of technical systems, formulated by Altshuler (Altshuler, 1984; Cavalluchi, 2001), can be applied for product development through a systemic analysis. Thus, each product is analyzed in terms of how it complies with these laws, and based on the identified gaps, conceptual solutions for improvement can be proposed. In the case of conceptual co-design, this activity is intended to be carried out by the development team (D) together with group A for product classes 1-4, and by the development team (D) together with groups A and B for product classes 5-7 (Fig. 7.25).

7.4. METHODS, TECHNIQUES, AND TOOLS APPLICABLE IN THE STAGE OF CO-ARCHITECTURAL DESIGN

In the stage of co-architectural design, the preliminary structure of the product is created, highlighting its subsystems and the connections between them, with the direct participation of potential clients/users, i.e., groups A and/or B, depending on the product class. The co-participation of groups A and/or B can take place during the steps of defining the product's subsystems, establishing the topography of the product subsystems/modules/subassemblies, and determining the degree of differentiation for various product variants where module combinations are made and extra options are defined.

7.5. METHODS, TECHNIQUES, AND TOOLS APPLICABLE IN THE DETAIL CO-DESIGN STAGE

Detailed constructive co-design is a stage of design in which the final or detailed design of the product is made, with the direct involvement of customers/consumers (groups A and/or B, depending on the product class). It is considered that, at this stage, special attention must be given to aspects related to design and ergonomics, which must be analyzed from multiple perspectives, together with specialists (A) and potential clients/users (B).

CHAPTER 8. DETAILED DESIGN OF THE METHODOLOGY FOR THE DEVELOPMENT OF CO-CREATED PRODUCTS

The chapter details the methodology for the development of co-created products, structured into stages, steps, and phases, through the integration of methods proposed by the author and techniques from the specialized literature.

8.1. STAGE 1. COMPETITIVE CO-DESIGN OF THE PRODUCT

This stage comprises three phases, each containing several sub-phases. The first phase, establishing the need and potential product, involves defining the unmet need by existing products, identifying the potential and generalized product. The development team (D) analyzes the context, opportunities, and defines the product mission (see fig. 8.1). The second phase, co-defining market requirements, involves identifying relevant stakeholders, while team D collects the "voice of the customer" through classical methods (interviews, questionnaires, focus groups). Advanced analyses regarding the evolution of requirements over time are applied, using laws formulated in the doctoral thesis and dedicated software applications. Co-defining the importance of requirements involves groups A (experts) and B (consumers), with the scores processed in application #1. Co-defining target values and classifying characteristics is a phase focused on product specifications and includes: Competitor analysis – determining the performance and specifications of rivals; Requirement-characteristic correlation – evaluated with application #2 through correlation scores; Setting target and limit values – performed using application #3, according to Taguchi methods and the Kano model; Kano classification – team D proposes attractive features for competitive advantage; Mathematical modeling – formal relationships between requirements and characteristics are defined, using algebraic structures and Kano/IF-Kano models for evolutionary predictions and the development of software applications.

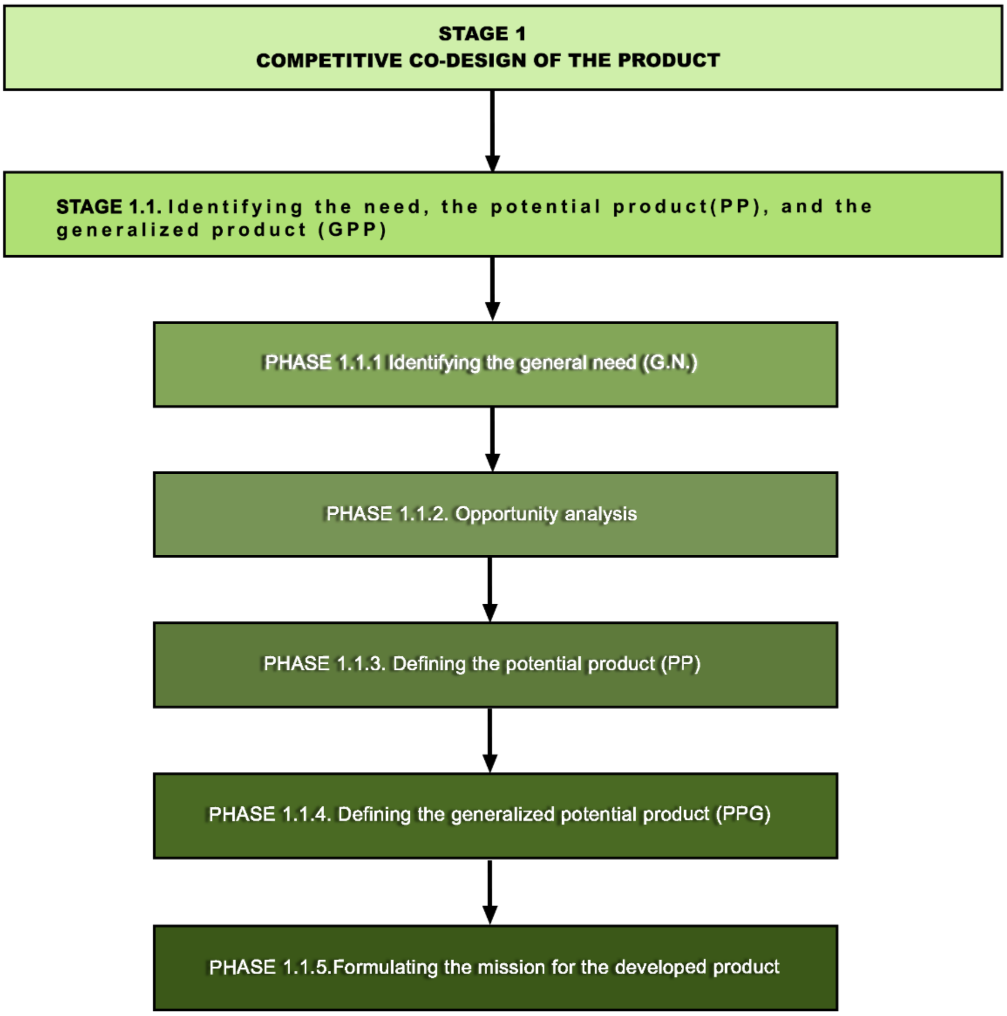


Fig. 8.1. Component phases of stage 1.1, establishing the need for the potential product and the generalized product

8.2. STAGE 2. FUNCTIONAL CO-DESIGN

The functional co-design stage consists of several steps as follows: establishing the product's mode of operation, determining the functional implications of requirements, identifying the main categories of functions, functional modeling, ordering and prioritizing functions based on their utility value, and identifying the phenomena through which the functions can be fulfilled. This stage is characterized by a lower degree of co-creation involvement. Except for step 2.5, all other steps are carried out exclusively by the development team. For step 2.5, which involves ordering and prioritizing functions according to their utility value, the participation of group A (experts) is considered important for product classes 1–4, and participation of both groups A and B (experts and customers) is important for product classes 5–7.

8.3. STAGE 3. CONCEPTUAL CO-DESIGN OF THE PRODUCT

The stage of conceptual co-design of the product involves going through several phases where concepts are co-generated using various methods, techniques, and applications adapted for co-created products. It includes the establishment of partial and total concepts, sorting of concepts, and finally, selecting the optimal concept. In the phase of co-generating partial and total concepts, a large number of concepts are generated, involving mixed teams (groups A and B) and multiple methods. Methods used include TRIZ, QFD, Taguchi, the Nine Screens method, ideality indicators (both classic and CREAX), laws of technical system evolution, Su-Field analysis, analogy, and extrapolation. Figure 8.10 shows the identification of some methodology phases within the structure of the House of Quality. For each critical function of the product, technical phenomena and principles are identified, resulting in multiple conceptual solutions. Through morphological analysis, the most feasible combinations are selected to form a catalog of integral concepts. Based on a simple application, from the resulting concept catalog, with the help of groups A and/or B, depending on the product class, four to eight concepts can be sorted. The optimal concept can be selected either through a specific application with the help of groups A and/or B or by applying the AHP (Analytic Hierarchy Process) method by the development team. This process results in the optimal concept, which will be further developed in detail.

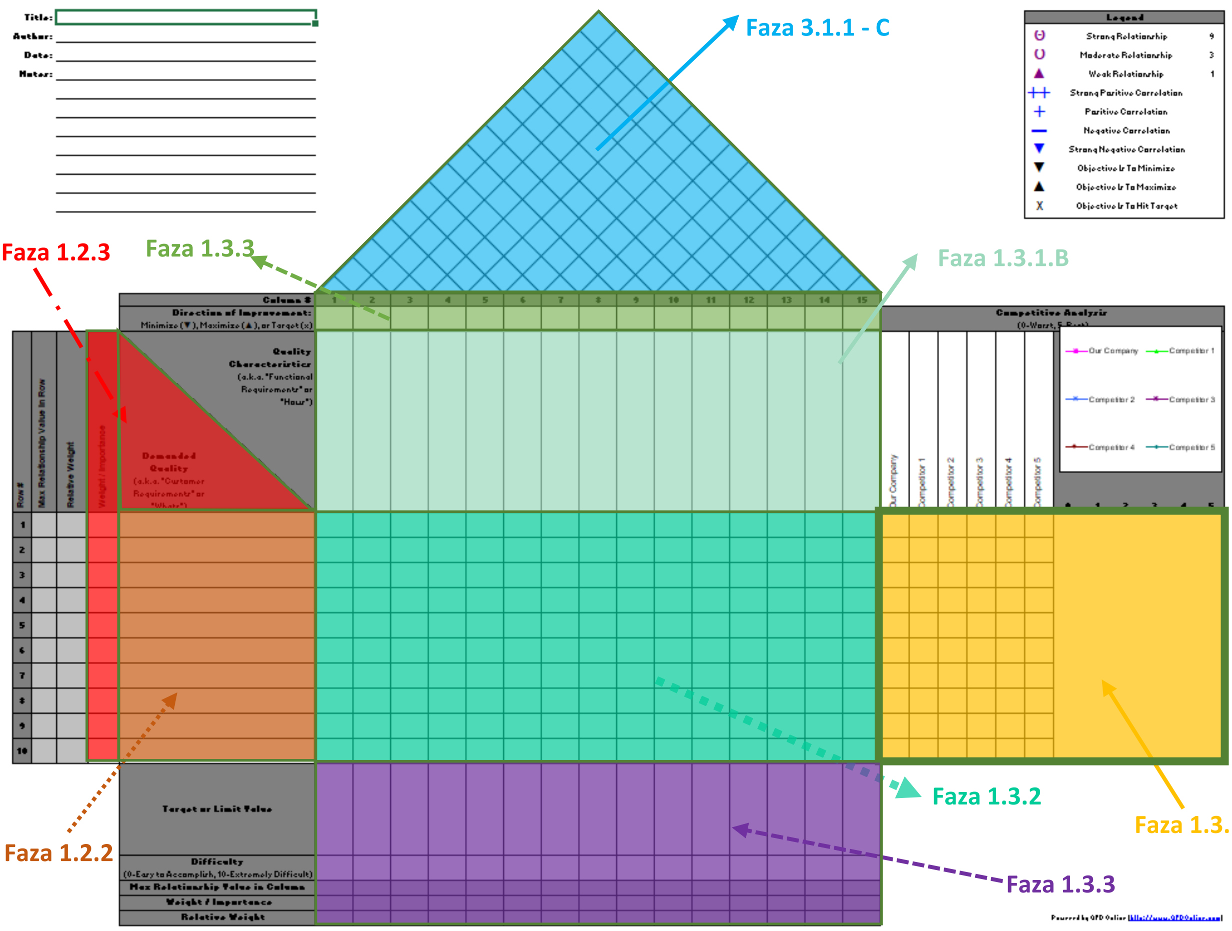


Fig. 8.10. Phases of the methodology corresponding to the House of Quality

Case Study No. 8.1. ***Natural System for Climate Control and Light Filtering*** **– Co-Establishment of Generic and Specific Conceptual Solutions Using the Su-Field Method**

1.Analysis and Understanding of the System (context)

The natural system for climate control and light filtering uses natural plants and passive elements (such as porous materials or translucent membranes) for air cooling (through evaporation, shading, or heat absorption) and also for light filtering (reducing intensity or diffusing UV rays).

2. Identification of Su-Field Components (S_1 and S_2)

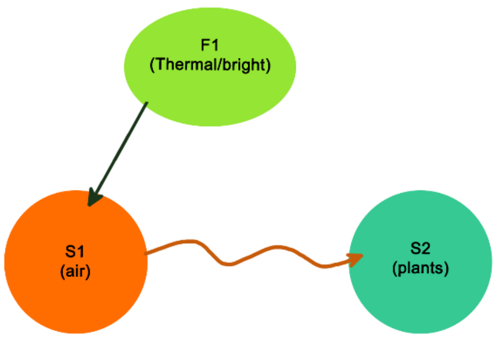
Substance	Equivalent Physical Element	Type of Su-Field
S_1	Room air	Substance
S_2	Plants / filtering materials / membranes	Substance
F (Field)	Natural field: thermal/light	Field

3. Evaluation of the current interaction (Fig. 8.12)

- If the system cools and filters effectively → Su-Field is complete and functional.
- If the filtered light is too weak or the air does not cool sufficiently → system is insufficient.
- If the plants completely block the light or retain excessive moisture → harmful effects.

4. Possible Su-Field transformations to improve the system (Fig. 8.13)

Identified Problem	Standard TRIZ – Su - Field suggested	Recommended Action
Cooling is insufficient	Addition of another field	Introduction of a controlled airflow
Light filtering is too intense	Replacement of S2 and/or F	Use of a plant arrangement with variable transparency
The humidity produced is excessive	Introduction of an absorbent S3	Addition of a hygroscopic material



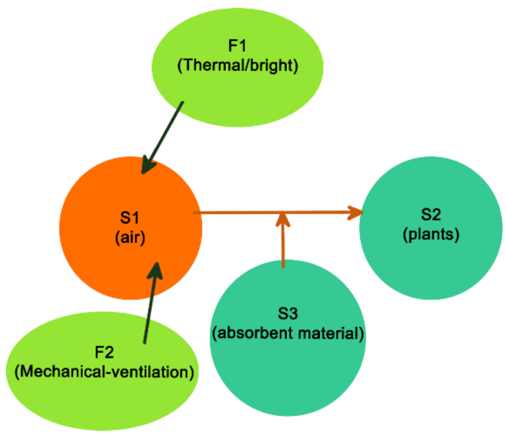


Fig. 8.12. Initial structure of the Su-Field system

Fig. 8.13. Improved structure of the Su-Field system

8.4. STAGE 4. ARCHITECTURAL CO-DESIGN

Architectural co-design represents the fourth stage in which the schematic model of the product is created, the product subsystems are established, the topology of the systems, modules/subassemblies is set, the interactions are determined, the degree of determination for different product variants is defined, the implications regarding manufacturing costs are assessed, and the final product architecture is established.

Co-defining the subsystems involves 11 essential phases: Establishing alternative modules – provides the user with flexibility in choosing the configuration; Degree of modularization – reflects customization possibilities and production efficiency; Procurement and standardization of subassemblies – contributes to efficiency, reduced costs, and inter-organizational collaboration; Co-defining the main subsystems – involves collaboration of the team with groups A and B, depending on product classes; Degree of simplicity – analyzed through indicators of modularity, standardization, and procurement; Proposals for unification and normalization – aimed at design optimization; Establishing consumable and wear elements – targets reliability, ergonomics, and sustainability; Degree of flexibility – evaluated through costs and adaptation time, as well as the capacity to fulfill multiple functions; Reconditioning, reuse, remanufacturing – essential criteria for sustainability and circular economy; Degree of adaptation – analyzed through customization possibilities and integration in other systems.

A topological optimization is carried out for efficient distribution of components, ensuring structural resistance and intuitive user experience. Product differentiation is achieved through combinations of modules and extra options, evaluated on functional, aesthetic, and technological criteria, using multicriteria methods.
Co-creation may increase initial costs, but reduces long-term commercial risks. The proposed cost model includes fixed, co-created, and outsourced components, with detailed cost calculation formulas depending on the number and type of variants chosen by clients. Based on all the previous stages, the final product architecture is established, which reflects the balance between functionality, costs, sustainability, and the preferences of the users involved in the co-creation process.

8.5. STAGE 5. DETAILED CO-DESIGN

Detailed co-design represents the final stage of the methodology developed in this thesis, including essential activities such as: sizing and precision, ergonomics, industrial design, material selection, stress verification, functional simulations, and the preparation of technical drawings.

9. CONTRIBUTIONS REGARDING THE DEVELOPMENT OF A NEW MODEL FOR PRODUCT PERSONALITY EVALUATION

9.1. THE NEED TO DEVELOP A NEW MODEL FOR PRODUCT PERSONALITY EVALUATION

Considering that the theory of personality congruence is controversial, as well as other critical aspects highlighted in Chapter 3, it is deemed necessary to develop a new model for evaluating product personality, adapted to the complex realities of the product development process in general, and of co-created products in particular.

9.2. DEVELOPMENT OF A NEW PRODUCT PERSONALITY EVALUATION MODEL – PERSONALITY – MOOD – COMFORT MODEL

Considering the shortcomings and controversies related to the theory of product personality congruence, this research proposes a new methodology that includes three major categories of indicators: product personality indicators (I), indicators associated with the mood induced by the product in the user (Mood) (J), and indicators regarding user comfort (K). To measure these indicators, a 7-point Likert scale was used, ranging from extremely low satisfaction (1) to extremely high satisfaction (7) (Likert, 2024)

.I. PRODUCT PERSONALITY INDICATOR- I

Personality is a complex concept that involves the aesthetic aspect, elements related to the identity of the product and brand, the emotional impact created by the product, the natural environmental impact, and the quality of the analyzed product. In this doctoral thesis, it is proposed to consider the significance and all aspects of personality as a key element in determining the personality indicators of a product within the field of industrial design. By thoroughly exploring the consumer-product relationship, the research aims to determine how different personality indicators influence users' perceptions and emotional responses.

Considering these aspects, it is proposed that the personality indicator represents a weighted sum of five main indicators, as follows (Table 9.1).

Table 9.1. Structure of the Indicators in the I-J-K Model

Major Indicator	Primary Indicators	Main Indicators	Tertiary Indicators
I - PRODUCT PERSONALITY INDICATOR	a. Aesthetic Indicator (Visual Appearance)- I_1	a1. Aesthetic Indicator (Visual Appearance)- I_{11}	I_{111}– Natural (Organic)
			I_{112} – Agreeable (Pleasant)
			I_{113} – Appropriate (Suitable)
			I_{114} – Functional (Usable)
		a2. Flow Indicator - I_{12}	I_{121} – Harmony (Beautiful)
			I_{122} - Proportion (Attractive)
			I_{123} - Balance (Symmetry)
			I_{124} - Shape and Color Matching (Fitting)
		a3. Color Indicator - I_{13}	I_{131} - Pleasant (Agreeable)
			I_{132} - Suitable (Appropriate)
			I_{133} - Meaningful (Obvious)
			I_{134} - Suggestive (Intuitive)
			I_{135} - Harmonizing
		a4. Texture Indicator- I_{14}	I_{141} - Functional (Usable)
			I_{142} – Aesthetic
			I_{143} -Appropriate Combinations (Proper Mixes)
	b. Product and Brand Identity Indicator– I_2	b1. Temporal Indicator- I_{21}	I_{211} – Past (Then)
			I_{212} – Present (Now)
			I_{213} – Future (Then)
		b2. Spatial Indicator- I_{22}	I_{221} – Rural (1) ←→ Urban (7)
			I_{222} – Cardinal Directions East (1) ←→ West (7)
			I_{223} – Home (1) ←→ Office (7)
			I_{224} – Outside (1) ←→ Inside (7)
		b3. Technological- I_{23}	I_{231} – Handcrafted
			I_{232} - Industrial
		b4. Authenticity- I_{24}	I_{241} – Authentic
			I_{242} – Derived
		b5. Sophistication- I_{25}	I_{251} – Simple
			I_{252} -Refined
		b6. Scale- I_{26}	I_{261} - Large scale
			I_{262} –Small scale
	c. Emotional Impact Indicator– I_3	Feeling of Adventure- I_{31}	I_{311} – Novelty
			I_{312} – Originality
			I_{313} – Stimulation to use / try / explore abilities
		Feeling of Independence- I_{32}	I_{321} – Freedom from constraints
			I_{322} – Freedom of movement
			I_{323} – Freedom of action
			I_{324} – Freedom of expression
		Feeling of Security- I_{33}	I_{331} – Safety (trust, absence of unforeseen situations) I_{332} – Security (absence of any possibility of physical/intellectual harm) I_{333} – Stability (constancy, invariability in response)
		Feeling of Sensory Stimulation- I_{34}	I_{341} – Visual
			I_{342} – Olfactory
			I_{343} – Tactile
		Feeling of Self-confidence- I_{35}	I_{351} –Self-worth validation
			I_{352} –Confirmation of one's qualities
		Feeling of Power- I_{36}	I_{361} – Authority (decisiveness, responsibility, command)
			I_{362} – Control (mastery of actions/situations)
			I_{363} – Supremacy (dominance, superiority, leadership position)
	d. Natural Environmental Impact Indicator- I_4	Preservation- I_{41}	I_{411} – Environmental neutrality
			I_{412} – Low energy consumption
			I_{413} – Low water consumption

		Recycling - I_{42}	I_{421} – Enables recycling
			I_{422} –Suitable for recycling
			I_{423} – Biodegradability
		Pollution - I_{43}	I_{431} – Environmental impact (low carbon footprint)
			I_{432} – Emission of pollutants
			I_{433} – Counteraction of polluting elements
	e. Surface quality indicator -I_5	Finishing - I_{51}	I_{511} – Remarkable
			I_{512} – Outstanding
			I_{513} –Worth mentioning
			I_{514} – Comparable
		Roughness - I_{52}	I_{521} – Functional
			I_{522} – Aesthetic
			I_{523} – Appropriate combinations
II. MOOD INDICATOR- J	J_1 - Friendliness	-	Hostile (1) ⟵⟶ Friendly (7)
	J_2 - Pleasantness	-	Disagreeable (1) ⟵⟶ Agreeable (7)
	J_3 - Calmness	-	Worried (1) ⟵⟶ Calm (7)
	J_4 - Relaxed	-	Tense (1) ⟵⟶ Relaxed (7)
	J_5 - Clarity	-	Confused (1) ⟵⟶ Clear (7)
	J_6 – Self-confidence	-	Insecure (1) ⟵⟶ Confident (7)
	J_7 - Enthusiasm	-	Apathetic (1) ⟵⟶ Enthusiastic (7)
	J_8 - Energetic	-	Lethargic (1) ⟵⟶ Energetic (7)
III. COMFORT INDICATOR - K	a. Ergonomics Indicator- K_1	Ease of Physical Use - K_{11}	K_{111} – Physical effort
			K_{112} – Position/posture
			K_{113} – Efficiency
			K_{114} – Ambidexterity
		Ease of Cognitive Use - K_{12}	K_{121} – Minimal mental effort
			K_{122} – Intuitiveness of use
		Safety in Use - K_{13}	K_{131} – Absence of risk
			K_{132} – Lack of hazard/chance events
			K_{133} - Stability
		Physical Comfort- K_{14}	K_{141} – Comfortable
			K_{142} – Easy
			K_{143} – Pleasant
			K_{144} – Handy
		Mental Comfort- K_{15}	K_{151} – Not demanding
			K_{152} – Relaxing
			K_{153} - Soothing
	b. Indicator of Social Environmental Impact- K_2	Physical Adequacy -K_{21}	K_{211} – Suitable for sports
			K_{212} – Suitable for outdoor movement
		Educational Adequacy -K_{22}	K_{221} – Children's education
			K_{222} – (Continual) adult education
		Recuperative Adequacy -K_{23}	K_{231} – Relaxation
			K_{232} – Recovery, convalescence
	c. Indicator of Durability – Reliability -K_3	Durability -K_{31}	K_{311} – Behavior during service life
			K_{312} – Operating cycles
			K_{313} – Lifetime (service life cycle)
		Reliability -K_{32}	K_{321} – Failure-free
			K_{322} –Low maintenance

a. Aesthetic Indicator (Visual Aspect) – I_1.

Aesthetics, as the primary vector of user perception, plays an essential role in defining the value of an industrial product, representing a balance point between functionality and visual expressiveness. Although controversial in the literature—where the axiom "form follows function" has often been criticized (Sareh, 2015)—aesthetics is today understood as a complex component involving visual, emotional, and sensory perceptions. In this research, the aesthetics indicator (I_1) is conceptualized as a weighted sum of four secondary indicators: shape (I_{11}), outline (I_{12}), color (I_{13}), and texture (I_{14}).

b. Product and Brand Identity Indicator – I_2.

Within industrial design, this indicator plays a key role in differentiating products on the market. It integrates elements such as visual appearance, functionality, materials used, as well as associated symbols or logos, contributing to building a coherent brand identity and communicating its values. Specifically, product personality is defined by traits such as innovation, reliability, or accessibility, directly influencing consumer perception and purchasing decisions. For a structured approach, indicator I_2 is detailed through six secondary sub-indicators, each reflecting a specific dimension of product identity:

- I_{21} – Temporal dimension: examines the product's connection with the past, present, or future, influencing its long-term relevance;
- I_{22} – Spatial dimension: analyzes the cultural and geographical usage context, influencing adaptability and market positioning;
- I_{23} – Technological dimension: distinguishes between handcrafted and industrial products, impacting perceptions of authenticity and efficiency;
- I_{24} – Authenticity: a key factor in building consumer trust and differentiating from derivative products;
- I_{25} – Sophistication: reflects the degree of complexity and refinement, defining target segments and quality perception;
- I_{26} – Scale: refers to production scale (large vs. small), influencing branding strategy and product accessibility.

These sub-indicators allow a detailed evaluation of product identity, supporting engineering and strategic efforts in designing products with a clear competitive advantage and strong identity in today's market context.

c. Emotional Impact Indicator – I_3.

The emotional impact indicator measures the ability of a product, service or brand to influence the user's emotional states, playing a vital role in building a strong consumer-brand relationship. Emotional impact directly contributes to customer loyalty (creating a strong product identity) and purchasing decisions (emotions triggered by product use). For this indicator, six secondary indicators have been proposed, addressing relevant aspects as follows:

- Sense of adventure (I_{31}): measures the product's ability to stimulate exploration and curiosity, associated with tourism, extreme sports, and off-road vehicles;
- Sense of independence (I_{32}): reflects products that allow users to act autonomously, contributing to a sense of personal control, common in technology and personal transport solutions;
- Sense of security (I_{33}): indicates products that offer protection and confidence, such as safety equipment and security systems;
- Sense of sensory stimulation (I_{34}): products that enhance sensory perceptions, such as perfumes, cosmetics and food products, creating a pleasant experience;
- Sense of self-confidence (I_{35}): describes the impact of products that improve users' self-esteem;
- Sense of power (I_{36}): reflects products that give users a feeling of control and authority, associated with high-performance business equipment or extreme sports.

d. Natural Environmental Impact Indicator – I_4.

This indicator analyzes a product's effect on the environment, addressing key aspects such as natural resources, biodiversity, pollution, and climate change. Evaluation can include material sustainability, recyclability, carbon emissions throughout the product lifecycle, and production efficiency, detailed as follows:

- Preservation (I_{41}): evaluates the product's impact on conserving natural resources, promoting durable and renewable materials and maximizing product lifespan to reduce waste;
- Recycling (I_{42}): analyzes the product's ability to be recycled or reused at the end of its life cycle, encouraging recycling processes and waste reduction;
- Pollution (I_{43}): measures impact on air, water and soil pollution throughout the product's life cycle.

e. Surface Quality Indicator – I_5.

This indicator measures the level of excellence of a product's visual and tactile finish, reflecting both aesthetic appearance and functional performance and durability. Two secondary indicators have been proposed for surface quality, addressing relevant aspects:

- Finishing (I_{51}): represents the final surface treatment to ensure a uniform and aesthetic texture, influencing visual appearance and product durability;
- Roughness (I_{52}): refers to micro-irregularities on the product surface, affecting performance through adhesion, friction, and wear, with both aesthetic and functional impact.

The main product personality indicator I is determined as a weighted sum of the five principal indicators I_1, I_2,...., I_5:

$$I = \sum_{n=1}^{5} \delta_n \cdot I_n \tag{9.2}$$

II. MOOD INDICATOR (Emotional States – "Mood") – J

In the design of products with personality and co-creation, understanding moods is essential because users' emotions impact creativity, collaboration and engagement in the development process. Eight indicators are proposed to evaluate product personality, correlated with users' emotional states. These eight indicators, reflecting the most relaxing moods, are presented in Table 9.7.

Table 9.7. Main Indicators of Product-Induced Mood

Main Indicator	Evaluation							Major Indicator J Calculation
J_1 - Friendliness	Hostile (1) ←→ Friendly (7)							$J = \sum_{k=1}^{8} \omega_k \cdot J_k$
	1	2	3	4	5	6	7	
J_2 - Pleasantness	Unpleasant (1) ←→ Pleasant (7)							
	1	2	3	4	5	6	7	
J_3 - Calmness	Worried (1) ←→ Calm (7)							
	1	2	3	4	5	6	7	
J_4 - Relaxation	Tense (1) ←→ Relaxed (7)							
	1	2	3	4	5	6	7	
J_5 - Clarity	Confused (1) ←→ Clear-minded (7)							
	1	2	3	4	5	6	7	
J_6 – Self-confidence	Insecure (1) ←→ Self-confident (7)							
	1	2	3	4	5	6	7	
J_7 - Enthusiasm	Apathetic/Bored (1) ←→ Enthusiastic (7)							

	1	2	3	4	5	6	7	
J_8 - Energy	Sluggish (1) ←→ Energetic (7)							
	1	2	3	4	5	6	7	

III. COMFORT INDICATOR– K

a. Ergonomics Indicato-K_1. The ergonomics indicator focuses on integrating ergonomic principles to create products that are comfortable, safe, and easy to use. It analyzes how design can be adapted to meet users' needs, optimizing the interaction between them and the product. This study proposes design solutions that combine ergonomics with product personality to improve satisfaction and usage efficiency, based on five secondary indicators:

- Physical ease of use (K_{11}) – Considers factors such as weight, dimensions, and shape;
- Cognitive ease of use (K_{12}) – Measures how easy it is for the user to understand and mentally operate the product;
- Safety in use (K_{13}) – Assesses the product's safety level, preventing accidents by minimizing mechanical, electrical or chemical risks;
- Physical comfort (K_{14}) – Refers to how well the product supports the user's physical needs, reducing fatigue and preventing long-term discomfort;
- Mental comfort (K_{15}) – Measures the product's impact on the user's mental and cognitive state, aiming to reduce stress and enhance the overall experience through intuitive and efficient design.

b. Social Environmental Impact Indicator – K_2.

This indicator measures a product's impact on the environment and community throughout its lifecycle, considering both ecological and social aspects. It promotes creating products that not only meet functional and aesthetic requirements but also comply with ecological and social standards, based on three indicators:

- Physical adequacy (K_{21}) – Analyzes how well a product meets ergonomic and functional requirements of the user, optimizing user-product interaction by adapting to user needs and usage environment;
- Educational adequacy (K_{22}) – Refers to the product's ability to support educational processes, stimulating learning and skill development either through specific functionalities or by promoting creativity and critical thinking;
- Recuperative adequacy (K_{23}) – Measures the efficiency of a product in supporting the user's physical or mental recovery process through ergonomic design adapted to the needs of those undergoing recovery.

c. Durability – Reliability Indicator – K_3.
This indicator refers to a product's ability to maintain performance and functionality over the long term under varying conditions of use, being essential for evaluating durability and reliability. It plays a crucial role in creating innovative products that meet sustainability requirements:

- Durability (K_{31}) – Refers to the product's resistance to physical wear and environmental conditions without significant damage or loss of functionality;
- Reliability (K_{32}) – Refers to the product's ability to operate correctly over the long term without failures under normal usage conditions.

The major comfort indicator (K) is calculated as a weighted sum of the three main indicators K_1, K_2, and K_3. It is integrated into a more complex system alongside the major personality (I) and mood (J) indicators to form the Personality – Mood – Comfort indicator (P-D-C), denoted by Ω.

$$K = \sum_{k=1}^{3} \delta_k \cdot K_k \tag{9.3}$$

The static three-dimensional vector model, mentioned in Chapter 5, allows expressing the P-D-C indicator as a vector combination of the three components (I, J, K), which helps define the personality of a product ensemble within a common environment.

$$\vec{\Omega} = (\mathrm{I}, \mathrm{J}, \mathrm{K}) = \mathrm{I} \cdot \vec{\mathrm{i}} + \mathrm{J} \cdot \vec{\mathrm{j}} + \mathrm{K} \cdot \vec{\mathrm{k}} \tag{9.4}$$

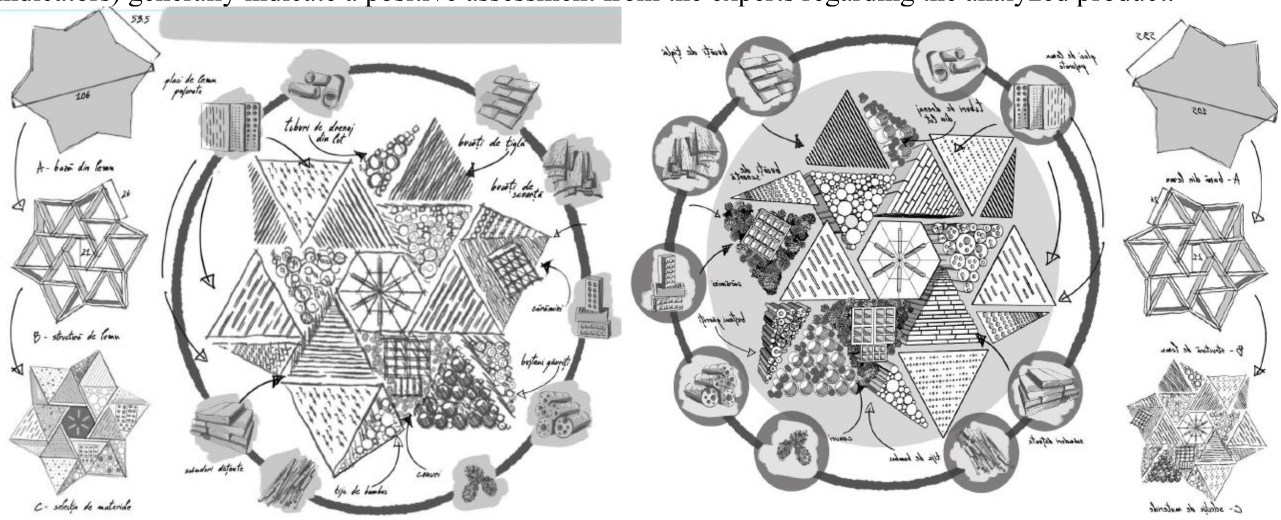
Considering the evolutionary framework from Chapter 5 and the laws of product evolution over time, it can be established that the P-D-C personality indicator, through its three components, is dynamic. On this basis, using the evolutionary three-dimensional vector model, relation (5.19) becomes:

$$\vec{\Omega}(\mathrm{t}) = \big(\mathrm{I}(\mathrm{t}), \mathrm{J}(\mathrm{t}), \mathrm{K}(\mathrm{t})\big) = \mathrm{I}(\mathrm{t}) \cdot \vec{\mathrm{i}} + \mathrm{J}(\mathrm{t}) \cdot \vec{\mathrm{j}} + \mathrm{K}(\mathrm{t}) \cdot \vec{\mathrm{k}} \tag{9.5}$$

Relation (9.5) can be used to study the evolution over time of a product ensemble within a common environmental context, which forms a unified whole, with the purpose of establishing its laws of evolution and, based on this, forecasting its future development and, respectively, determining the next generation of products, with their personality as the main focus.

9.3. EVALUATION OF A PRODUCT'S PERSONALITY BASED ON THE PERSONALITY – MOOD – COMFORT MODEL

To demonstrate the viability of the product personality evaluation methodology proposed in subchapter 9.2, a relevant product in the current environmental protection context was chosen — an insect hotel (Fig. 9.2). The results obtained from applying two comprehensive questionnaires (one for a group of 14 experts and the other for a group of 88 potential beneficiaries, with ratings on a 1–7 Likert scale for all 100 indicators) generally indicate a positive assessment from the experts regarding the analyzed product.



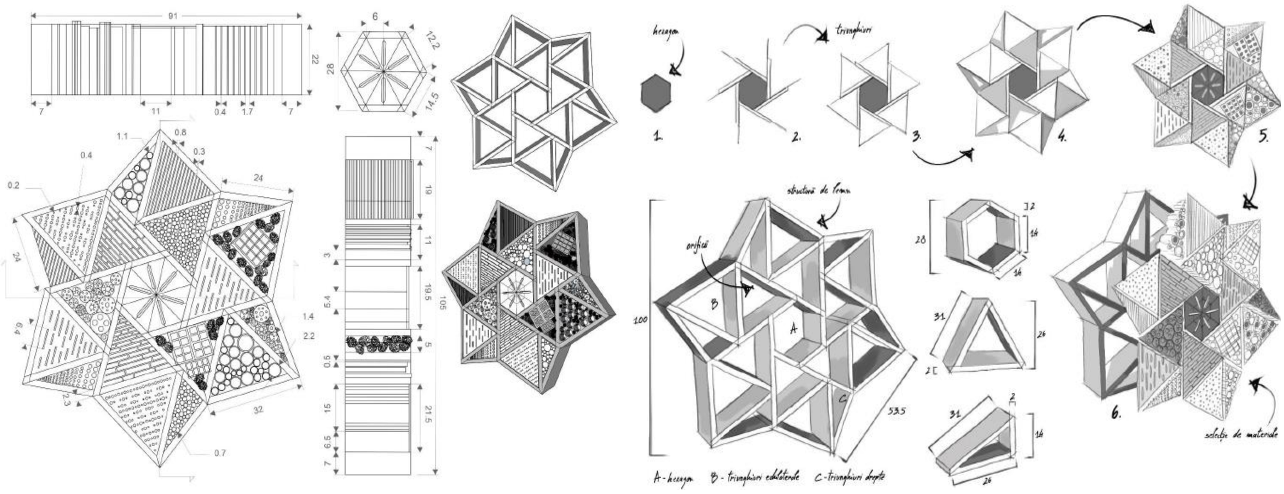


Fig. 9.2. Insect hotel designed by the author for the evaluation of the product's personality

Based on the indicators presented in subchapter 9.2, two questionnaires were conducted: one applied to a group of 14 experts (A) and another to a general audience of 88 people (B). The results are as follows:

A. Experts Group – Results

- Product Personality Indicator – I = 5.652
- Mood Indicator – J = 6.457
- Comfort Indicator – K = 5.637

It can be observed that the three indicators have relatively high values (above average), ranging between 5 and 7, which means that the experts considered the analyzed product to have a relatively high level of personality, mood and comfort.

B. Grupul potențialilor beneficiari - Rezultate

- Product Personality Indicator – I = 5.914
- Mood Indicator – J = 6.033
- Comfort Indicator – K = 5.868

It can be observed that, in the case of potential beneficiaries, the personality indicator and the comfort indicator have slightly higher values, while the mood indicator has slightly lower values compared to the similar data obtained for the experts' group. Based on these data, using the complex three-dimensional model presented in Chapter 5, the relationships for the complex P-D-C indicator can be written for the two cases mentioned above:

$$\overrightarrow{\Omega_A} = (5.562, 6.457, 5.637) = 5.562 \cdot \vec{\imath} + 6.457 \cdot \vec{\jmath} + 5.637 \cdot \vec{k} \quad \text{...... (9.6)}$$

$$\overrightarrow{\Omega_B} = (5.914, 6.003, 5.868) = 5.914 \cdot \vec{\imath} + 6.003 \cdot \vec{\jmath} + 5.868 \cdot \vec{k} \quad \text{...... (9.7)}$$

Using relations (9.6) and (9.7), a general relationship for the P-D-C indicator can be established by weighted summation of the three pairs of indicators obtained for Group A and Group B, respectively. Thus, considering the public utility of the evaluated product, a weight of 0.4 is proposed for the experts and 0.6 for the potential users. Table 9.17 presents the calculation of the weighted indicators.

Table 9.17. Calculation of Weighted Indicators

I	I_A	I_B	α_{IA}	α_{IB}	$\Omega = \alpha_{IA}I_A + \alpha_{IB}\, I_B$
	5.562	5.914	0.4	0.6	5.775
J	J_A	J_B	α_{JA}	α_{JB}	$\Omega = \alpha_{JA}J_A + \alpha_{JB}\, J_B$
	6.457	6.003	0.4	0.6	6.186

K	K_A	K_B	α_{KA}	α_{KB}	$\Omega = \alpha_{KA}K_A + \alpha_{KB} K_B$
	5.637	5.868	0.4	0.6	5.775

On this basis, the indicator of the P-D-C model developed in this work, weighted across the two groups, will have the following expression:

$$\overrightarrow{\Omega_{A-B}} = (5.775, 6.186, 5.775) = 5.775 \cdot \vec{i} + 6.186 \cdot \vec{j} + 5.775 \cdot \vec{k} \quad (9.8)$$

CHAPTER 10 – FINAL CONCLUSIONS AND CONTRIBUTIONS REGARDING THE DEVELOPMENT OF CO-CREATED PRODUCTS WITH PERSONALITY

10.1. FINAL CONCLUSIONS

The study of the current state of research and achievements regarding the development of co-created products and products with personality, as well as the research conducted within the doctoral thesis, allows for the formulation of the final conclusions of the work, which can be summarized as follows. The conducted research highlighted the importance of developing co-created products and products with personality, perceived personality and user involvement in co-creation as essential factors for market success. Functionality and price remain important but are not sufficient in the absence of an emotional relationship between the user and the product. The integrated use of methods such as Kano, QFD, FMEA, DFC-DBC, GoNano principles, and open innovation models enables the effective translation of customer expectations into product features. Additionally, methods such as the Jordan model, Dumitrescu, surveys, and psychometric evaluations contribute to defining product personality through emotional reactions and perceptions. The specialized literature shows that the congruence theory, which states that users prefer products that reflect their personality, is both supported and criticized. Although it is an important framework in studying consumer preferences (Aaker, 1999; Sirgy, 1982; Kleine & Kernan, 1991), the theory requires a more nuanced approach that also includes motivations such as aspiration, identity contrast and situational influences.

The mathematical models developed in this doctoral thesis address the evolving customer requirements and product characteristics, based on the importance to the customer and the frequency with which the customer requests a specific feature, highlighting several laws of evolution including the law of idealizing requirements, the law of increasing dynamics of requirements, the law of relating requirements, the law of fusion, etc. The developed co-creation methodology includes 26 stages grouped into 5 phases, involving three categories of actors: the development team (D), experts (A), and users (B). The methodology is supported by numerous tools applied in concrete case studies, facilitating co-decision-making regarding requirements, functions, target values and conceptual solutions, including creativity stimulation methods such as those associated with TRIZ. Although it may increase initial costs due to investments in user interaction tools and increased production complexity by implementing user solutions (modules, extra options, iterations, etc.), in the medium and long term, co-creation brings significant savings by reducing commercial risk, better aligning the product with market needs, reducing costs related to marketing, research and development, service and training, customer loyalty, and boosting sales.

The new product personality evaluation model, called the personality-mood-comfort (P-D-C) model, developed within the doctoral thesis, with 100 indicators grouped into three categories (3 major indicators, 16 main indicators, 31 secondary indicators and 100 tertiary indicators), eliminates the shortcomings of the personality congruence theory criticized by many authors. By applying the new personality-mood-comfort model to the insect hotel product, through centralizing the responses of a group of 14 experts and a group of 88 potential beneficiaries, and implementing the complex three-dimensional model, the feasibility of this model is demonstrated, along with the possibility of using the complex personality-mood-comfort indicator for studying the evolution over time of a product ensemble in a common environmental context. This forms a unified whole with the aim of establishing its evolution laws and, on based on this, forecast future development and, respectively, determine the next generation of products, with their personality at the forefront.

10.2. MAIN CONTRIBUTIONS REGARDING THE DEVELOPMENT OF CO-CREATED PRODUCTS AND PRODUCTS WITH PERSONALITY

In relation to the current state and directions of research and development regarding co-created products and products with personality, the primary objective of the research and development activity within the doctoral thesis was established as: the elaboration of a methodology for the development of co-created products based on a set of appropriate methods, techniques, tools, and applications, as well as a new model for evaluating product personality that includes aspects related to user-induced mood and comfort, aiming to increase customer satisfaction.

The doctoral thesis brings significant contributions in the field of co-created products and products with personality, integrating theoretical research and practical applications, as follows:

- A bibliometric study (1990–2024) highlighting the growing interest in co-created products in the specialized literature;
- Development of five mathematical models (both static and evolutionary) for analyzing customer requirements and product characteristics, including a model based on Kano's model;
- Formulation of six laws regarding the evolution of requirements, supported by three case studies;
- Design of a methodology consisting of 26 steps grouped into five stages, involving the development team, experts and users;
- Definition of the "6 CO" Model (CO-realization, CO-laboration, CO-improvement, CO-design, CO-munication and CO-development), defining five types of co-design;
- Definition of seven product classes and seven degrees of co-creation, which serve to establish how the methods, techniques, tools, and applications developed in the thesis are applied, and the level of involvement of the three actor categories: development team (D), expert group (A) and potential user group (B);
- Development of a relatively large number of methods, techniques, tools and applications, where TRIZ elements were adapted to facilitate contributions from expert groups and user groups in creating co-created products and products with personality (11 applications);
- Adaptation for co-created products and implementation in case studies and the methodology of several methods, techniques and tools from the Theory of Inventive Problem Solving (TRIZ): Contradiction Matrix, the 39 Parameters, the 40 Inventive Principles, the concept of technical contradiction, ideality evaluation indicators, the Nine Screens method, the 8 laws of technical system evolution, Su-Field analysis;
- Development of 12 applied case studies demonstrating expert and user involvement in co-designing a climate control and light filtration system;
- Implementation of a software prototype tested by 10 experts and 30 users for co-creation applications;
- Creation of a new, complex model for evaluating product personality, called the Personality-Mood-Comfort model (P-D-C), featuring 100 indicators grouped into three categories (3 major indicators, 16 primary indicators, 31 secondary indicators, and 100 tertiary indicators), developed based on a critical analysis and overcoming shortcomings of the personality congruence theory criticized by many authors;
- Demonstration of the feasibility of the P-D-C model, and the possibility of using the complex indicator associated with this model, combined with the complex three-dimensional model for studying the temporal evolution of a set of products within a common ambient environment forming a unified whole The purpose of this is to establish the laws of its evolution and, on this basis, forecast future evolution and determine the next generation of products, with a focus on their personality, based on applying the model to the insect hotel product, centralizing the responses of a group of 14 experts and a group of 88 potential beneficiaries.

The obtained results establish a methodology applicable to organizations, contributing to the market success of co-created products. The thesis offers a useful framework for researchers and practitioners in industrial design, supporting user involvement in the innovation process. Additionally, future research directions are proposed, such as:

- Extending the methodology to other product classes;
- Developing AI-based software applications;
- Advanced cost modeling in the context of co-creation;
- Further research on the study of temporal evolution of a set of products within a common ambient environment forming a unified whole, to establish the laws of evolution and, based on this, forecast future evolution and determine the next generation of products using the P-D-C model.

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