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MODULARITY SOLUTIONS WITHIN A MATRIX OF FUNCTION AND FUNCTIONALITY (MFF)

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Original scientific paper

In order to present new possibilities within preliminary design of product development, the objective of this paper is to present new concepts of modularity within Matrix of Function and Functionality (MFF). Design concept is based on a descriptive matrix which is further based on the generative model and the criteria for describing products, functions and functionalities. The purpose of using the modularity of the MFF is to improve the initial design process, where only the most basic information is available, such as functions and functionalities, and to use the general functionality method, which is not quite possible with the known morphological matrix. The modularity inside the MFF is based on the mutual relation between the function and the functionality, representing the data definition. In relation to the morphological matrix it is built and defined on the basis of a mathematical model and pre-set rules [1], not just on the basis of design intuition. This work represents a method for solving the modularity with regard to the shape and the function. This should facilitate the generation of the functional and shape structures of new and variant products. The developed MFF modularity model was implemented into a prototype web application and confirmed on a concrete product – the Active Lounge Chair 1.

Keywords: *design process, matrix of function and functionality, functional modeling, function and shape modularity, modular design*

Rješenja modularnosti unutar matrice funkcije i funkcionalnosti (MFF)

Izvorni znanstveni članak

Da bi se predstavile nove mogućnosti u okviru pripremnog projekta razvoja proizvoda, cilj je ovoga rada predstaviti nove koncepte modularnosti unutar matrice funkcije i funkcionalnosti (MFF). Projektni koncept bazira se na opisnoj matrici koja se dalje zasniva na generativnom modelu i kriterijima za opisivanje proizvoda, funkcija i funkcionalnosti. Modularnost MFF-a koristi se u cilju poboljšanja inicijalnog postupka konstruiranja, gdje su dostupne samo najosnovnije informacije, kao što su funkcije i funkcionalnosti, i korištenja općeg modela funkcionalnosti, što nije sasvim moguće s poznatom morfološkom matricom. Modularnost unutar MFF-a zasniva se na uzajamnom odnosu između funkcije i funkcionalnosti, predstavljajući definiciju podataka. U odnosu na morfološku matricu izgrađena je i definirana na osnovu matematičkog modela i prethodno postavljenih pravila [1], ne samo na osnovu konstrukcijske intuicije. Ovaj rad predstavlja metodu za rješavanje modularnosti u odnosu na oblik i funkciju. To bi trebalo olakšati generiranje funkcionalnih i oblikovnih konstrukcija novih i varijantnih proizvoda. Razvijeni model modularnosti MFF-a upotrijebljen je u prototipnoj web aplikaciji i potvrđen na konkretnom proizvodu – Stolici s aktivnim naslonjačem.

Ključne riječi: *konstrukcijski proces, matrica funkcije i funkcionalnosti, funkcionalno modeliranje, modularnost funkcije i oblika, modularni projekt*

1
Introduction

Because of the complex nature of modern technology, it is now rarely possible for an individual to tackle design and development of a major new product single-handed. In order to increase the probability of success of a new venture, the design process must be planned carefully and executed systematically. In particular, an engineering design method must integrate the many different aspects of designing in such a way that the whole process becomes logical and comprehensive [1]. In order to solve a technical problem we need a system with a clear and easily reproduced relationship, between inputs and outputs (Fig. 1). To that end it is always useful to make a block diagram in which the process and sub-systems inside a given block (black box) are at first ignored (Fig. 1).

With the purpose of solving technical problems different methods were developed [2]. Many authors present rules for design in various situations (Glegg, 1960; Woodson, 1966) as well as general methodologies (Alger and Hayes, 1964; Hill, 1970; Ostrofsky, 1977; Starr, 1963). These techniques are either algorithmic, which apply design rules or classification methods to a specific situation, or are not generalizable. They lack fundamental principles that can be applied to all design situations. The most easily generalized among these is the morphological technique by Zwicky [3, 4], which concerns itself with the intrinsic

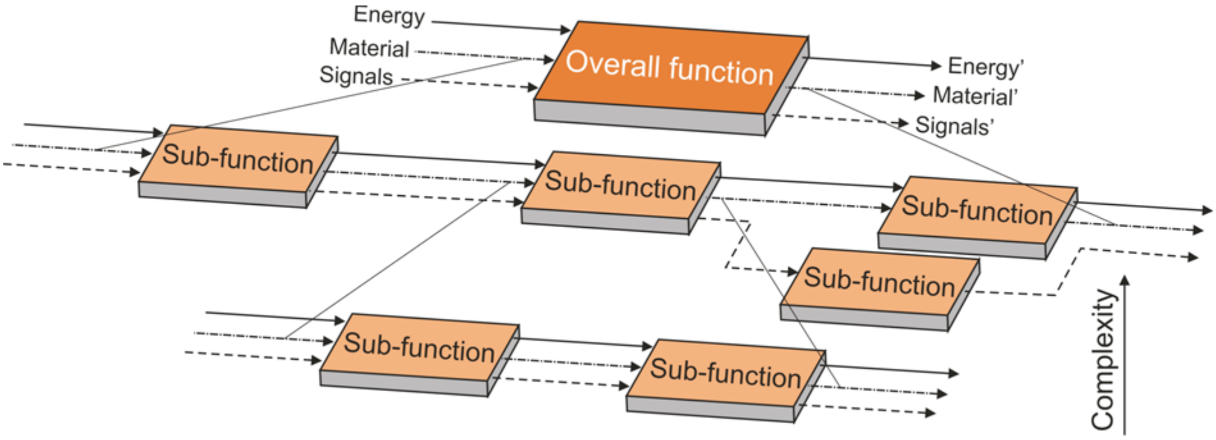


Figure 1 Establishing a function structure by breaking down an overall function into sub-functions

structural characteristics of the formation and content of the thought process. In [5, 6, 7] matrix models were presented, which enable the generation of a functional structure of the product, described in matrices. The background of most matrix models is represented by morphological box [3], which forms the basis for further development.

In order to generate the product's shape structures, new functional structures are essential. To generate them, important philosophies of engineering of technical functions must be considered [8, 9]. In [10], the authors approach describing the functions by defining the terminology that is related to the names of the functions, while others describe the functions of technical systems by means of physical laws [11]. With a view to unique identification, rules were defined [5], by means of which the functions, functionalities and products are described. The reference points for designing these rules are those presented in [12]. The functions are described by parameters, based on physical laws, which form the basis for the development of a mathematical model through which the connection with functionalities is established.

Research and development activities within the product-development process have their own characteristic and distinctive features, dominated by unpredictability, creativity, mentality and abstraction. Due to these features it is difficult to thoroughly describe, develop and implement the design process in the initial phases of computer-tools development [13, 14].

1.1
Market and function requirements

Today's market requires ever shorter development times for new products, which triggers the need for a modular architecture of products. Such a modular architecture makes it possible to combine one or several functions in the functional structure with one element that solves them [15]. Such an approach has several advantages, the main one being an increased number of product variants [16]. Erixon [17] developed the Modular Function Deployment method, using the Module Indication Matrix. The established rules [1] also include modularity rules in terms of the function and modularity with regard to the shape.

Market requirements are the basis for defining basic functional requirements, which in turn represent the initial information on a new potential product [18, 19]. At the beginning of the design process, functional requirements are usually unarranged, incomplete and sporadically presented, which makes them necessary to be arranged, complemented and expanded. By means of structural enlargement of functions, product structure can be presented as a functional structure, which is at the same time the basis for defining the shape (physical structure) of the product [13].

2
Matrix of Function and Functionality
2.1
The MFF concept

The Matrix of Functions and Functionalities (MFF) is a method, which represents a tabular representation of bindings between function requests and functionalities (Fig. 2) [20]. It is built and defined on the basis of a mathematical model and pre-set rules [5], not just on the basis of design intuition. It can be devised if key elements are known, such as initial functional requirements and functionalities.

Functional requests are derived from market requirements and represent the most important attributes of the requested system – functions, while functionalities are represented by technical systems [9] or shape models that in part or in whole fulfill the required functions.

Within the MFF, functional requirements are introduced into the relation on one side and functionalities on the other one, as shown in Fig. 2. Both functions and technical systems can be either simple or more complex, which depends on the initial description of individual systems.

The MFF is used when we want to improve the initial engineering process, where only the basic information is available. It represents a tool with which it is possible in the preliminary phase to concurrently solve several functional requirements and generate new functional and design structures of a product - development of brand new products as well as for the development of variant design.

The MFF concept upgrades and updates the deficiencies of up to know known methods like the morphological matrix [3], where using a small number of rows and columns yields a large number of solutions, which often makes them poor and unsuitable.

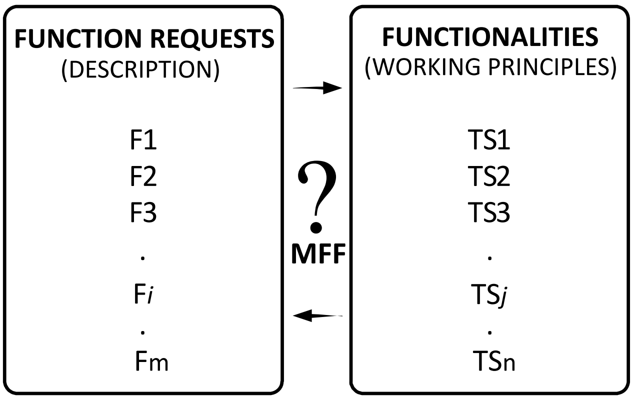


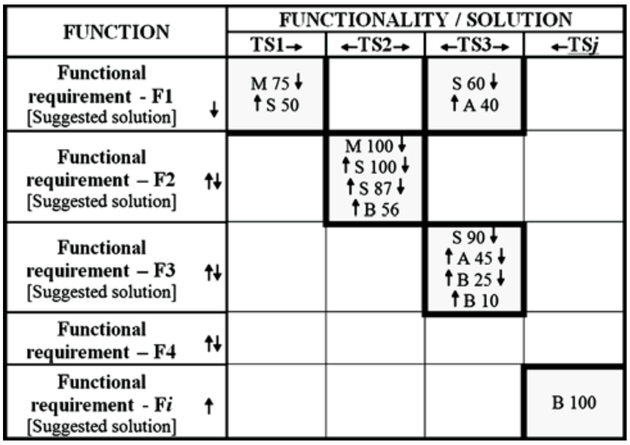
Figure 2 MFF – Bindings between function requests and functionalities

2.2
The detailed MFF overview

Detailed concept of MFF method is presented with theoretical and general descriptions of functions and technical systems [20]. Looking at Fig. 3, representing a detailed MFF model, we can see that functions or functional requirements are generally marked with Fi and are placed in the first column, while individual technical systems (functionalities) are marked with TSj and can be found in subsequent columns.

In the MFF model, technical systems are marked with general marks TS1, TS2,…,TSj; j=1,…,n, while in the case of implementations and concrete examples the marks are replaced by concrete, real names of technical systems.

Functions, defined in the MFF matrix, are described in the first column in the table, labeled Function. Each function fills a new line. In order to present the model, function names are marked with general marks, such as: F1, F2,…, Fi; i=1,…,m, while in concrete examples within an implementation, the marks are replaced by concrete, real names. Functions are defined on the basis of required functional requirements. For systematics and modularity reasons, they are described in input lists.



FUNCTION	FUNCTIONALITY / SOLUTION			
	TS1→	←TS2→	←TS3→	←TS*j*
Functional requirement - F1 [Suggested solution] ↓	M 75 ↓ ↑ S 50		S 60 ↓ ↑ A 40	
Functional requirement – F2 [Suggested solution] ↑↓		M 100 ↓ ↑ S 100 ↓ ↑ S 87 ↓ ↑ B 56		
Functional requirement – F3 [Suggested solution] ↑↓			S 90 ↓ ↑ A 45 ↓ ↑ B 25 ↓ ↑ B 10	
Functional requirement – F4 ↑↓				
Functional requirement - F*i* [Suggested solution] ↑				B 100

Figure 3 MFF with sub-matrices

The MFF vision is that solving the matrix should gradually lead to defining more and more information for a particular functional requirement or function, and that it is solved at the end of the process with a suitable functionality. With a view to fulfilling the function, the differences between particular variants are arranged and the modularity is built. Two crucial aspects are taken into account: fulfilling as many requirements as possible and fulfilling the requirements as effectively as possible. Both aspects are achieved through consistent combination of solution elements, bindings and modularization.

The links between the functions and the functionalities that solve them are created by means of the so-called sub-matrices. These sub-matrices are colored and highlighted in grey (Fig. 3). Fig. 3 shows several different sub-matrices, within which complexity of solving is explained. As a rule, sub-matrices are not logically distributed at the beginning as their internal distribution is determined by how the design process develops and by the presupposed number of functions and functionalities. Parts of the matrix significantly deviating from the main diagonal are usually evidence that the determined function does not have an accurate basis, that it is specifically oriented and cannot be directly applied in a particular variant. This is a way to determine an unjustified description of function and to develop opportunities for further arranging and modularity.

The MFF model within the design process always includes all the sub-matrices that are of key importance for the development of further designing. Sub-matrices involving at least one possible solution on at least one function within the presupposed technical system or functionality are full and display a partial and complete result for this sub-matrix, while the unsolved sub-matrices are not displayed. The result is displayed in the form of percentage values – numbers in a sub-matrix cell. The value is calculated on the basis of a verbal algorithm of the functional requirement's crossed values and the function on the functionality. Each displayed value corresponds to the informative type of the current function. The function type is based on the description and is determined from the characterized character set M, S, A, B (initial letters for main, supplementary, auxiliary and binding functions).

The number of functions within the sub-matrix is analogous to the number of possible solutions in the functionality column. Results-wise, only the functions with a specific, possible solution are displayed. The functions that are not solving a given situation are not included in the display.

Each technical system can have a different number of functions. For definition and uniqueness reasons, each function of a particular technical system in the MFF matrix is described by parameters, winning parameters and value intervals. However, it is not certain that it will be displayed as it has been mentioned above that it is displayed only when it solves a given functional requirement with a significant probability. Depending on the complexity of the function, it can be described by one or more parameters. In no case can it happen that a function could be left with no parameters, since a function without parameters is no longer a function.

3
MFF modularity solutions

In order to reduce the time required for arranging and improving the functional requirements, a MFF modularity model was developed. The objective of MFF modularity development is to upgrade and update the deficiencies of the morphological matrix in the areas of modularity, the use of a mathematically based model for creating the links between the function and the functionality, the use of faster and better development of solutions, the possibility of the automatic suggestion of solutions, and use of sub-matrices with the modularity. With the modularity model designers are able to manage the design process faster and better, particularly in the initial concept phases.

The key feature of the MFF is its arranging ability and the modularity of the sub-matrices. The result of arranging implies the modularity and/or the growth of the product's complexity. The fulfillment of variants for particular functions should always be ensured. In this case we are determining the number of functions that are fulfilled by a particular variant. This is how to confirm the gradation from the biggest to the smallest possible fulfillment of a function, and to establish a possible connection. We can look for modularity by shape or specifically determine the modularity by functions. This is achieved by providing a fulfillment for a particular variant in one of the adjacent variants. It establishes the modularity by functions, which makes it possible to use different technical systems for identical functions.

Modularity can be devised if we know the key elements, such as the basic list of functional requirements and a list of functionalities. The modularity model was created by expanding the matrix of functions and functionalities model, shown in [12], and by examining the functionality as it depends on various functions. The basis for generating and arranging the MFF is the functional structure of a product, which at the same time represents the matrix input. When developing a new product, it is not possible to know and be familiar with a detailed functional structure right at the beginning. Such a structure can be obtained and built only from a rough functional structure, which is subject to constant changes during the design process, as shown in [7].

Two types of modularity are taken into the account inside modularity model: modularity with regard to function and modularity with regard to shape.

3.1
Modularity with regard to shape

Modularity with regard to shape is referred to as the appearance of a product in one or more variants (versions). According to the shape-modularity principle [18], products can be pooled into modular assemblies.

They are checked in terms of the number of their functions that fulfill individual product variants, i.e., we are determining how many functions are fulfilled by a particular variant. In the case that a product variant includes all the functions of another variant, as well as the functions that other variants do not possess, that variant can replace the other one. A comparatively larger number of functions, fulfilled by a particular variant in comparison to another variant with a smaller number of functions, reflect a greater complexity of the variant. For the final confirmation of the variant with a larger number of functions it is later necessary to upgrade it and carry out an economic analysis, which has not been dealt with in this part because it is too extensive.

	FUNCTIONALITY			
FUNCTION	Variant 1	Variant 2	Variant 3	Variant 4
Function 1	+	+	+	+
Function 2	+	+	+	+
Function 3	+	+	+	
Function 4	+	+		
Function 5		+		
Function 6				

Figure 4 Modularity with regard to shape

Fig. 4 shows that variant 2 entirely replaces variant 1, as it fulfills all the functions that are fulfilled by variant 1. Compared to variant 1, variant 2, in turn, solves some other – additional – functions that the adopted variant does not solve. It can be argued that variant 2 is more sophisticated, compared to variant 1, and that it solves more functions. A back-to-back examination of variants 3 and 4 also reveals that variant 3 entirely replaces variant 4.

	FUNCTIONALITY			
FUNCTION	Variant 1	Variant 2	Variant 3	Variant 4
Function 1		+	+	+
Function 2	+	+	+	+
Function 3	+	+	+	
Function 4	+			
Function 5		+		
Function 6				

Figure 5 Modularity with regard to shape realized by new variant

If individual variants (1 and 2, for example) have common function, a new variant (variant 3) should be generated. This variant should fulfill all the functions not common to variants 1 and 2 (Fig. 5). An economic analysis has not been dealt with at this point because it is too extensive. In the case of modularity with regard to function, the functions are pooled for the larger number of variants. This ensures the use of various technical systems for identical functions. Two products with identical functions and not yet established functions require confirmation of their potential diversity. Only one product should be selected if no additional function has been confirmed for two functionally identical products.

3.2
Modularity with regard to function

Within the functional structure, more than one product can have identical or similar functions for performing the same or similar process. For such cases it is necessary to check the technical system overload by introducing modularity with regard to function. The modularity function consequently pools the functions for the larger number of variants. Function pooling represents the introduction of modularity according to the principle of function, where the use of various technical systems for identical functions is protected. For two products with identical functions, and in the case of non-established functions, it is vital to confirm their potential diversity. Only one product should be selected if no additional function has been confirmed for two functionally identical products.

	FUNCTIONALITY			
FUNCTION	Variant 1	Variant 2	Variant 3	Variant 4
Function 1	+	+	+	+
Function 2	+	+	+	+
Function 3	+	+		
Function 4	+		+	+
Function 5		+	+	
Function 6		+	+	

Figure 6 Modularity with regard to function

In Fig. 6, variants 1 and 2 solve functions 1, 2 and 3. These are two different technical systems that solve their common functions.

In the case of modularity with regard to shape, products are pooled into modular assemblies. They are checked in terms of the number of functions that fulfill an individual product variant, i.e., we are determining the number of functions that are fulfilled by a particular variant. The variant that includes all the functions of another function plus some new, additional functions is selected as the end product. The model does not include any econometric analyses that would confirm the economic feasibility of such a selected variant. Using modularity with regard to shape, it is possible to check the complexity of the product variants and the complexity of the process itself by means of the designer's self-verification. The variant that fulfills more functions is more complex and more sophisticated compared to the variant with a smaller number of functions.

4
Implementation

Although the design of a product must often be done in a multidimensional world, engineers are often taught concurrent techniques for the one-dimensional world. They do not know how to think in several dimensions because they have not been given the tools and techniques that can deal with that problem of a complex world.

The gap between research and practice is of concern today. Effective methods need to be developed for transferring research results to industry, therefore MFF modularity model was developed and verified with real application and products (Fig. 7).

Figure 7 Active Lounge Chair 1 – ALC 1

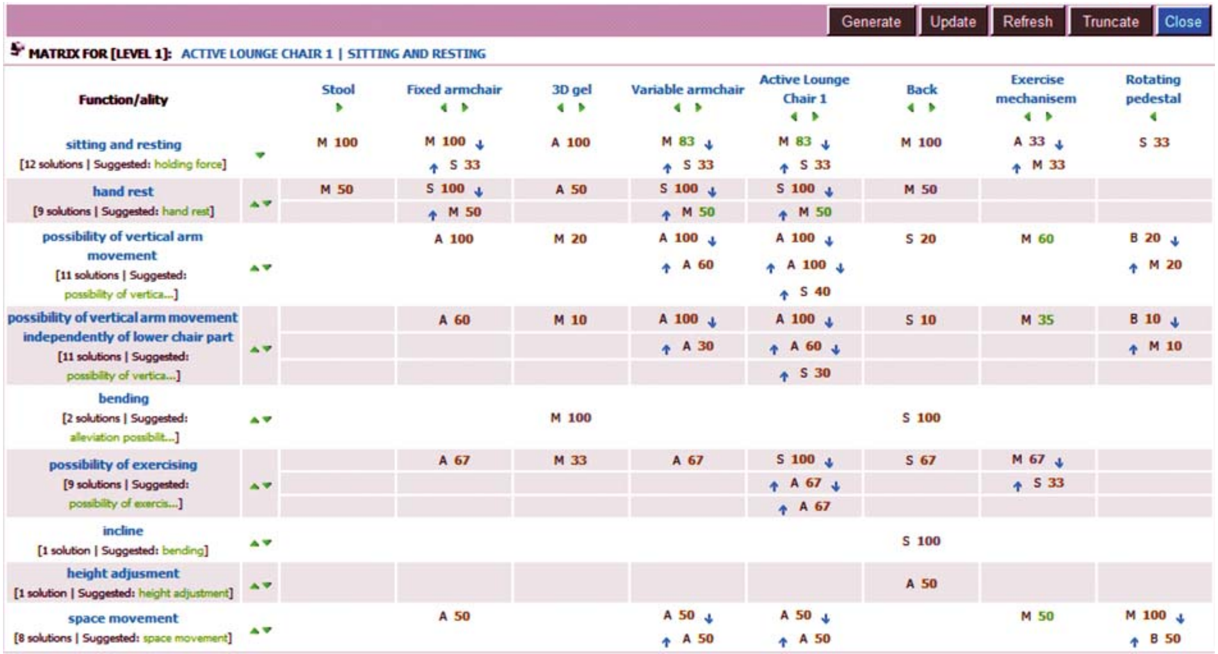
The modularity concept has been included and implemented into a developed Web database management system / application. The application is designed to be available from anywhere over the world, therefore it is based on Web technologies and centralized, relational database. The application supports individual work and work in virtual teams. With the concern of safety and accessibility of the data, suitable hardware and software systems were established. Application manages all of the engineering and concurrent data for the development of new preliminary products. According to the ERD diagram, current database consist of 23 different relations, where functions, functionalities and parameters occupy the largest available data space.

The MFF model is currently presented and implemented on more than twenty completely different, solved and described products from diverse design areas. For the purposes of this work, implementation will be shown on a developed product named *Active Lounge Chair 1 – ALC I*. The goal of the presented implementation is not to demonstrate a complete *ALC I*, but to show important aspects of modularity on different assembly parts of the chair.

The idea of *ALC I* is to represents a product whose basic functions are *sitting*, *resting* and *exercising*. It is aimed at a wide range of users of all ages, where also elderly people are encouraged to exercise and consequently achieve greater vitality in old age. Research and development of *ALC I* has strived to achieve that the product shape is esthetically correct, emanates comfort, is functionally and anatomically harmonious, is easy to use, is suitable from the ergonomic point of view, is practical and finally adaptable to anyone. The key components of the *ALC I* are: *the sitting part*, *the leg/foot rest, the arm/hand rest*, *the upper body rest*, and *the hand and leg exercise mechanism*, as shown in Figs. 7 and 9, where each one of the components allows and fulfills a precisely defined function. Figs. 7 and 9 are composed of several individual pictures that precisely and clearly show the design thinking behind the chair concept, particularly the leg rest with the exercise option.

The MFF in Fig. 8 represents the real MFF modularity design view of *ALC I* design. The matrix involves several possible solutions, cross-corresponding to several functions. The main possible functionalities are *Stool*, *Fixed Armchair*, *Variable Armchair, Active Lounge Chair 1*, etc. among which it is possible to manipulate the desired functions or functional requirements: *sitting* and *resting*, *hand rest*, *possibility of vertical arm movement*, *possibility of vertical arm movement independently of lower chair part, possibility of exercise, bending, height adjustment etc*.

A product can appear in one or more variants, which can be pooled into modular assemblies according to the principle of shape modularity or the principle of function modularity. The basic feature of shape modularity is to establish how many functions are fulfilled by each product variant. For ex.: Fig. 8 reveals that the *Fixed armchair* variant completely replaces the *Stool variant*, as it solves the *Stool's* main function (*sitting* and *resting*), as well as another function: *hand rest and the possibility of vertical movement*, which is by default not fulfilled by the *Stool*. The function solution within the technical system is shown as a percentage value in cells, i.e., cross-intersections in the matrix. The displayed value can be highlighted in various colors, depending on the quality of the sought-after data that can be found within different function types. The probability of a suitable solution hierarchically follows in colors from the most probable green to brown and the least probable grey. Compared to the *Variable armchair variant*, the *ALC I variant* solves some other, additional functions that the former variant does not solve by default. It can be



MATRIX FOR [LEVEL 1]: ACTIVE LOUNGE CHAIR 1 | SITTING AND RESTING

Function/ality		Stool ▶	Fixed armchair ◀ ▶	3D gel ◀ ▶	Variable armchair ◀ ▶	Active Lounge Chair 1 ◀ ▶	Back ◀ ▶	Exercise mechanisem ◀ ▶	Rotating pedestal ◀
sitting and resting [12 solutions | Suggested: holding force]	▼	M 100	M 100 ↓ ↑ S 33	A 100	M 83 ↓ ↑ S 33	M 83 ↓ ↑ S 33	M 100	A 33 ↓ ↑ M 33	S 33
hand rest [9 solutions | Suggested: hand rest]	▲▼	M 50	S 100 ↓ ↑ M 50	A 50	S 100 ↓ ↑ M 50	S 100 ↓ ↑ M 50	M 50		
possibility of vertical arm movement [11 solutions | Suggested: possibility of vertica...]	▲▼		A 100	M 20	A 100 ↓ ↑ A 60	A 100 ↓ ↑ A 100 ↓ ↑ S 40	S 20	M 60	B 20 ↓ ↑ M 20
possibility of vertical arm movement independently of lower chair part [11 solutions | Suggested: possibility of vertica...]	▲▼		A 60	M 10	A 100 ↓ ↑ A 30	A 100 ↓ ↑ A 60 ↓ ↑ S 30	S 10	M 35	B 10 ↓ ↑ M 10
bending [2 solutions | Suggested: alleviation possibilt...]	▲▼			M 100			S 100		
possibility of exercising [9 solutions | Suggested: possibility of exercis...]	▲▼		A 67	M 33	A 67	S 100 ↓ ↑ A 67 ↓ ↑ A 67	S 67	M 67 ↓ ↑ S 33	
incline [1 solution | Suggested: bending]	▲▼						S 100		
height adjusment [1 solution | Suggested: height adjustment]	▲▼						A 50		
space movement [8 solutions | Suggested: space movement]	▲▼		A 50		A 50 ↓ ↑ A 50	A 50 ↓ ↑ A 50		M 50	M 100 ↓ ↑ B 50

Figure 8 MFF modularity implementation view on the example of ALC 1

argued that the *ALC I variant*, compared to all three other variants, is more sophisticated and fulfills more functions. The *ALC I* is actually the only modular end solution that fulfills all the set functions according to the shape-modularity principle. It can also be argued that if a product variant includes all the functions of another variant, as well as the functions that the other variant does not possess, that variant can replace and substitute it.

On the other hand, modularity by functions can be specifically determined by providing fulfillment for a particular variant in one of the adjacent variants. It provides the possibility of using different technical systems for identical functions, which means that the real function *hand rest* corresponds to all the functionalities, except *Stool*, therefore the functional requirement *sitting* and *resting* corresponds to all the set solutions. The *ALC 1* functional variant completely covers all of the other three variants and so they can be replaced by the said variant. The replacement should be confirmed by an econometric study and technical fulfillment alone is not the only condition.

The *ALC I* modularity development resulted also in assembly optimization, where we managed to reduce the number of required parts. This reduction was achieved through MFF sub-matrices and function structures, where we discovered some superfluous overlapping functions and parameters. Those functions and parameters were combined, removed, merged and modularly modified. With the new design we managed to reduce the general assembly for 5 unique elements. Three changes took place on the attachment systems and two on mechanical movement sub-assembly.

5
Conclusion

Modularity within the MFF is based on the mutual relation between the function and functionality, which represents the data definition. The presentation is aimed at direct users, developers and researchers of technical systems and recognized technical processes. It is based on the connection between the recognized natural processes in nature and searching for comparable or satisfying technical processes at a certain level of knowledge development. The mission of the developed models is to contribute to, and find within, the initial design processes the appropriate fundamentals for better and faster design development.

The MFF upgrades and updates the deficiencies of the morphological matrix through the application of mathematically- not intuitionally based model for creating links between the function and functionality. MFF and MFF modularity model allow concurrent solving of several open functional requirements, which recognizes requirements for productivity, clear recognition of generators, binders and information users, and reduction of design and development times. Modular solving of functional requirements is widespread also in the areas of self-assessment, auto-solving or automated suggesting of solutions and the possibility of using modularity of individual sub-matrices.

According to the complexity of the *ACT I* assembly, different solutions and possibilities were found (Fig. 9). Some modularity solutions were very promising and gave us new insights for the future, others were contrary defined, which we managed to solve and understand through MFF self-verification and few were not presented at all, which gave us the opportunity to look for errors or missing functions, functionalities.

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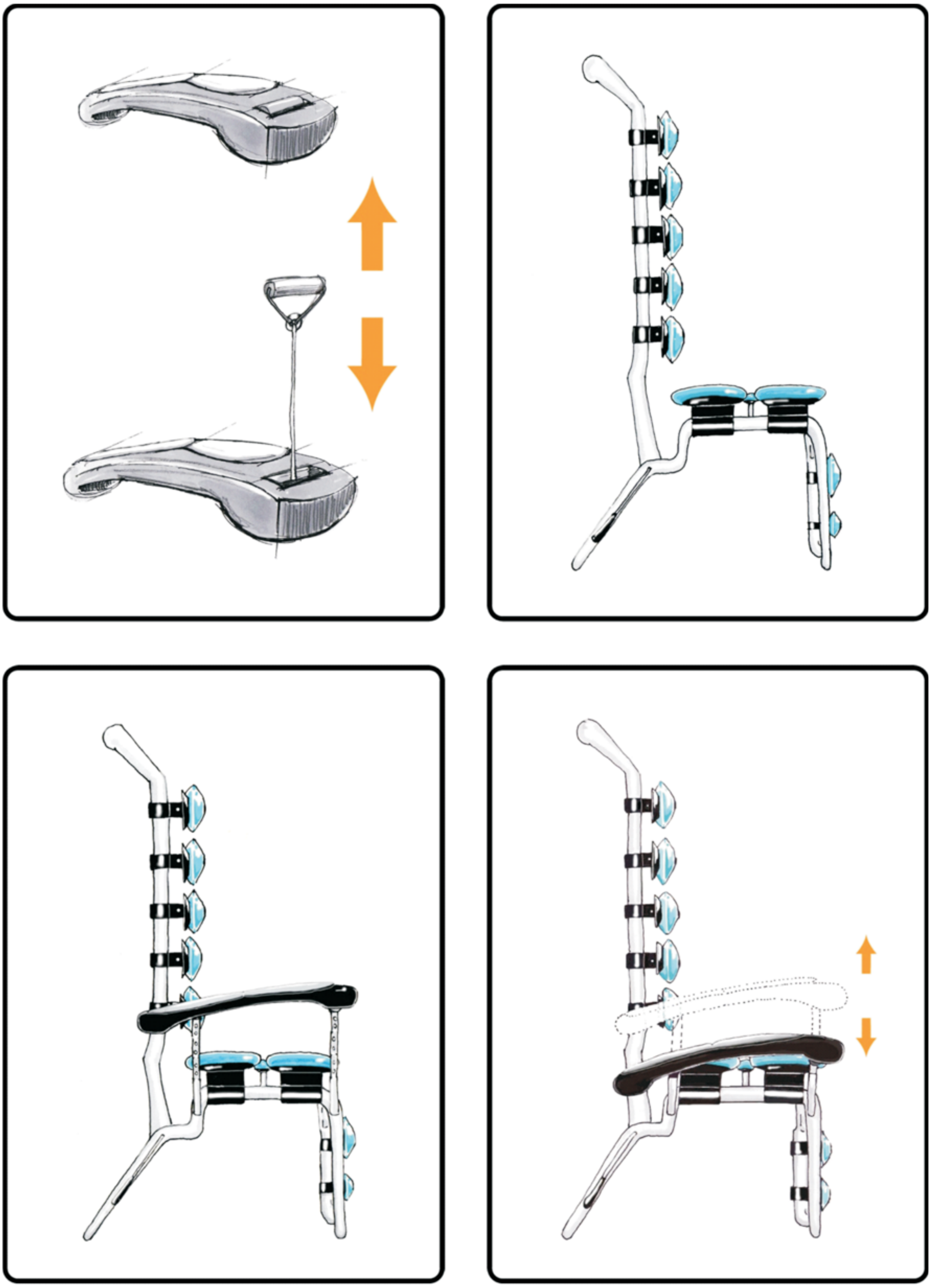

Figure 9 Few design sketches of new solutions

6
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