ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Mehmet Mert KAVUZLU

INVESTIGATING THE SUCCESS OF A NEW SYSTEMATIC PRODUCT DESIGN APPROACH ON EXAMPLE DESIGNS

DEPARTMENT OF MECHANICAL ENGINEERING

ADANA-2016

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

INVESTIGATING THE SUCCESS OF A NEW SYSTEMATIC PRODUCT DESIGN APPROACH ON EXAMPLE DESIGNS

Mehmet Mert KAVUZLU

MSc THESIS

DEPARTMENT of MECHANICAL ENGINEERING

We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on ..../..../2016.

....	....	....
Prof. Dr. Necdet GEREN SUPERVISOR	Prof. Dr. Melih BAYRAMOĞLU MEMBER	Asst. Prof. Dr. Kerimcan ÇELEBİ MEMBER

This MSc Thesis is written at the Department of Institute of Natural And Applied Sciences of Çukurova University.
Registration Number:

Prof. Dr. Mustafa GÖK
Director
Institute of Natural and Applied Sciences

This thesis was supported by the Scientific Research Project (BAP) of Çukuova University under grant No. FYL-2016-6061

ABSTRACT

MSc THESIS

INVESTIGATING THE SUCCESS OF A NEW SYSTEMATIC PRODUCT DESIGN APPROACH ON EXAMPLE DESIGNS

Mehmet Mert KAVUZLU

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF MECHANICAL ENGINEERING

Supervisor : Prof. Dr. Necdet GEREN
Year: 2016, Pages: 181
Jury : Prof. Dr. Necdet GEREN
: Prof. Dr. Melih BAYRAMOĞLU
: Asst. Prof. Dr. Kerimcan ÇELEBİ

There are many design methodologies to provide systematic product and machine design (Pahl et al. 2007, French 1999; Cross 2008, Otto and Wood 2000; Ulrich and Eppinger 2007; Ullman 2009). In this context, one of the most important stage of machine design process is the concept generation (Buynas and Nispett 2011). Morphological design methodology is one of the most useful methods to use during concept generation stage. Best design solution can be reached between the options which are offered. However, there has been considerable criticism of this design process model. Because, many possible combinations and different solutions can be obtain by multiplying of all function alternatives with one another. Only one or two of these design alternatives is practicable for production stage. Hence, concept design stage which is most important step of machine design stage does not complete easily during product design stage.

In this study, we applied some modifications to morphological product design to achieve a new and different systematic product design methodology.

Three different products will be used for performance measurement of a new approach to systematic product design and comparison with morphological design methodology. All of these methodologies will be apply to three products and the success of new approach will be obtain comparatively.

Key Words: Design Methodologies, Systematic Design, Morphological Design, Concept Generation, Machine Design

ÖZ

YÜKSEK LİSANS TEZİ

YENİ BİR SİSTEMATİK ÜRÜN TASARIM YAKLAŞIMI BAŞARISININ ÖRNEK TASARIMLAR İLE İNCELENMESİ

Mehmet Mert KAVUZLU

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
MAKİNE MÜHENDİSLİĞİ ANABİLİM DALI

Danışman : Prof. Dr. Necdet GEREN
Yıl: 2016, Sayfa: 181
Jüri : Prof. Dr. Necdet GEREN
: Prof. Dr. Melih BAYRAMOĞLU
: Yrd. Doç. Dr. Kerimcan ÇELEBİ

Sistematik ürün ve makine tasarımı sağlayan birçok tasarı yöntemi geliştirilmiştir (Pahl et al. 2007, French 1999; Cross 2008, Otto and Wood 2000; Ulrich and Eppinger 2007; Ullman 2009). Bu kapsamda, kavram geliştirme aşaması makine tasarım prosesinin en önemli adımlarından biridir (Buynas and Nispett 2011). Morfolojik tasarım ise tasarımın kavram geliştirme aşamasında kullanılan en yararlı yöntemlerden biridir. Sunduğu çözüm seçenekleri arasında ulaşılabilecek en iyi tasarımı barındırır. Morfolojik yaklaşım, tasarımcılara sunduğu bu katkı beraberinde ciddi bir dezavantaj da getirir. Bunlardan en önemlisi her fonksiyon için belirlenen çözüm sayılarının tüm fonksiyonlar için bulunan çözüm sayıları ile çarpımı kadar çözümün elde edilmesidir. Bu çözümlerden sadece 1 veya iki tanesi uygulanabilir çözümü içermektedir. Bunun sonucu olarak, makine tasarım sürecinin en önemli basamağı olan kavramsal tasarım aşaması, ürün tasarım sürecinde kolay bir şekilde tamamlanamamaktadır.

Bu çalışmada, morfolojik ürün tasarım yöntemi uygun değişiklikler ile geliştirilerek yeni ve farklı bir sistematik ürün tasarım yönteminin başarısı araştırılacaktır.

Modifiye edilmiş morfolojik yöntemin başarısını ölçmek ve konvansiyonel morfolojik yöntemle karşılaştırmak için üç adet farklı ürünün tasarım aşamaları kullanılacaktır. Her iki yöntem her üç ürüne uygulanarak denenecek ve yeni yöntemin başarımları karşılaştırmalı olarak elde edilecektir.

Anahtar Kelimeler: Tasarım Yöntemleri, Sistematik Tasarım, Morfolojik Matris, Kavram Geliştirme, Makine Tasarımı

ACKNOWLEDGEMENTS

I would like to special thank to my advisor Prof. Dr. Necdet GEREN, for his advises, supports, guidance and especially endless encouragements during my MSc Thesis study.

I would like to thank to Çağdaş SARIGÜL for criticism and support throughout this work.

Finally, I am forever indebted to my family for their supports and encouragements.

CONTENTS **PAGE**

LIST OF TABLES **PAGE**

LIST OF FIGURES **PAGE**

1. INTRODUCTION

Starting point of engineering design is necessity of new product development. New product development (NPD) is commonly known as a significant source of competitive advantage, and emphasis is being placed on systems which simultaneously provide quality, variety, frequency, speed of response to customer request. However, pressure is placed upon NPD systems to work with a wider portfolio of new product opportunities and to manage the risks associated with progressing these through development to launch owing to shorter life cycles and request for greater product variety. To get through this, attention has focused on systematic screening, monitoring and progression frameworks.

The development of new products requires more than mindfulness of the issues; specialised skills, knowledge, processes, mind-sets, problem solving mechanisms and management philosophies are needed (Bessant and Francis, 1997).

The new product development process consists of five stages. One of the best ways to understand the activities of each stage is shown below. This way is to array the process stages. These stages are;

- Concept Stage
- Definition & Business Case Stage
- Development Stage
- Testing Stage
- Deployment Stage

The goal of the concept stage is to evaluate a new product opportunity. Concept evaluation activity will be carried out by a product leader with support from others in the organization as needed. The deliverable in concept stage is the product concept proposal which is presented to the Product Review Board at the concept review.

The purpose of the definition and business case stage is to describe the product which will be developed, and to accomplish the business plan for the product. While the definition and business case stage, the external assumptions made during the previous stage are approved through additional market research and competitive analysis. Engineering assumptions will be approved in this stage by more extensive design and feasibility experiments.

The aim of the development stage is to develop the product based on the agreement and development plan approved at the Business Plan review. Development stage comprises the major design/development steps such as software and hardware development, tooling, packaging design and prototype building.

The purpose of testing stage is to complete product testing and analyse the preparedness for mass production. Testing stage includes some sub stage such as pilot manufacturing, testing and manufacturing process validation.

The final stage of the New Product Development Process is the deployment stage which includes the remaining steps required for full general release of the product. This stage also includes enhance to mass production, marketing and launch plan implementation, distribution and support.

Many organizations are modifying the process to facilitate rapid development methods, where customer feedback is requested throughout the development cycle to allow for quicker adjustments.

Steps of engineering design that provides new product will be investigated in the following sub-sections.

1.1. Engineering Design

Engineering design is a complex process and thinking and creating new products and/or adapting something old to solve a problem. However, from the viewpoint of the ABET (Accreditation of Engineering and Technology), engineering design is the process of arrangement a system, component, or process to meet desired needs. It is an innovative, iterative and decision-making process, in which the basic sciences, mathematics, and engineering sciences are applied to optimally convert resources to meet a stated objective. Among the fundamental elements of the design process is the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.

The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statement and specifications, production processes, concurrent engineering design, and detailed system description (Haik and Şahin, 2011).

Design problems are generally more unclear described than analysis problems. The solution of the design problem is a system having specified properties, whereas the solution to the analysis problem consisted of the properties of a given system. To design a simple journal bearing, the designers have to consider many parameters such as fluid flow, heat transfer, friction, energy transport, material selection, thermomechanical treatments, statistical descriptions, and etcetera. Design problem solution is therefore open ended (Budynas and Nisbett, 2011).

The design problem solution requires a process. There are probably as many processes of design as there are engineers. Therefore, this study does not present guidebook approach to design but presents a general application of the problem-solving methodology related with the design process.

1.2. Engineering Design Process

Many design processes involve repeating the same steps because of that reason, best design process provide the designer to learn the fundamentals of design process, easily apply it over and over again as the design evolves from the concept to the detail phase. A good design process should be simple, flexible, and applicable to just about any problem one can think of.

The whole process of engineering design, from start to finish, is often outlined as in Figure 1.1. to begin design process, first stage is determination of deficiency. After the implementation of many stages, the process arrives at the conclusion with the presentation of the plans for satisfying the need. Depending on the nature of the design process, several design phases may be repeated throughout the life of the product, from inception to termination. Budynas and Nisbett (2011) examines steps of the design process in detail in several sections.

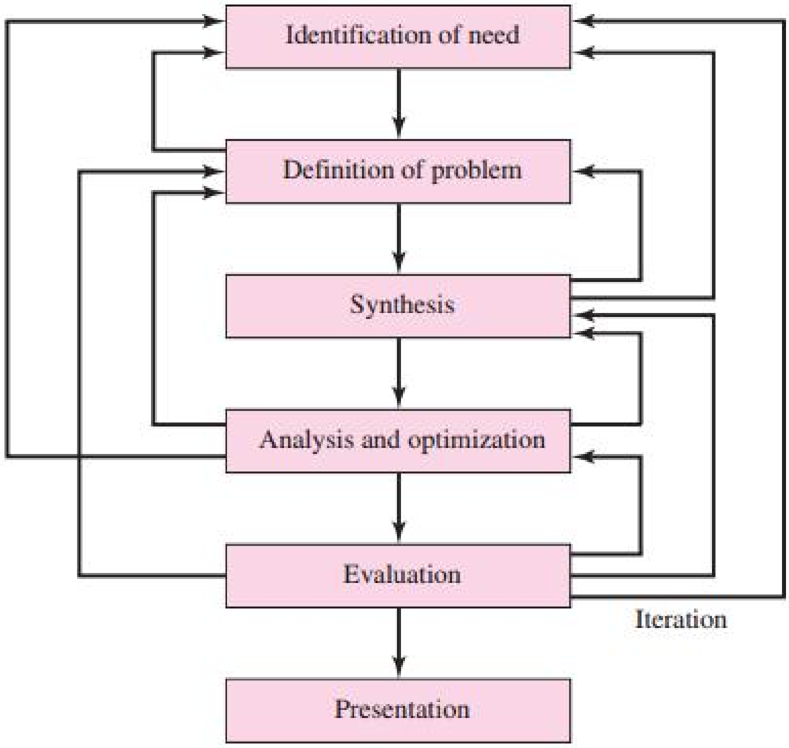


Figure 1.1. Steps of engineering design process (Budynas and Nisbett 2011)

The engineering design process starts with identification of needs. Most important stage of “identification of needs” step is to obtain customer demand. Almost in every company, a customer may submit a request for developing an artefact. It is often unlikely that the need will be expressed clearly. The customer may know only the type of product which he/she desires.

The next step of engineering design process is definition of problem. This step generally involves a listing of the product and/or customer demands and specially information about product functions and properties in comparison with other properties of product. Problem definition is one of the most important and critical stages of engineering design process because definition of problem step provides to guide all subsequent analysis and decision-making. Creating a clear definition of a design problem is more difficult than, defining an analysis problem.

The definition of a design problem may evolve through a series of steps as develop a more complete understanding of the problem.

The synthesis which is third step of engineering design process, of a scheme connecting possible system elements is sometimes named as the invention of the concept. This is the first and most important stage of the synthesis. Several schemes must be proposed, investigated, and quantified in terms of established metrics. System schemes that do not survive analysis are overviewed, improved, or disposed. The potentials are optimized to determine the best performance of which the scheme is capable (Budynas and Nisbett, 2011).

The forth step of engineering design process is analysis and optimization. In this part of engineering design process, the synthesis step has been completed and the analysis and optimization step begins. This step also known as “Detailed Design”. In essence, the design solution must be experimented against the physical laws. The manufacturability of the designed product also must be checked to provide its usefulness. A new product design may fulfil the physical laws, but if it cannot be manufactured, it is a useless product design. This step is put in iterative sequencing with the original synthesis phase. Often, analysis requires a concept to be redefined then reanalysed, so that the design is constantly shifted between analysis and synthesis. Analysis starts with estimation and is followed by order of magnitude calculation. Estimation is based on experience rather than education. Order of magnitude analysis is a rough calculation of the specified problem. Because of that reason, the order of magnitude does not provide an exact solution, but it gives the order in which the solution should be expected (Haik and Şahin, 2011).

Evaluation stage is very substantial phase of engineering design process. In this stage of design process, successful design is proofed and comprised the testing of a prototype in the laboratory. Thus, evaluation stage provides the design engineer with strong tools for the preparation of innovative products. To detect the product whether successful or not, the designers ask some questions about product such as “Is it reliable?”, “Easy and economical to manufacture?”, “Can it fulfil the requirements of customer?”, and etc. If the answer of these questions are positive, design process passes next step.

A product design is a description of an object and a prescription for its construction. Because of that reason it will have existence to the extent that it is denoted in the available modes of communication. The presentation of the design process may include design portfolios, journals, drawings, graphics, reports and verbal presentation. Presentation is the vital stage of engineering design because it provides to prove its innovative and superior performance. Hence, successful presentation effects selling performance. If this stage of engineering design process does not be successful, the time, effort, and cost spent on obtaining the solution have been largely wasted. Indeed, the designers also sell themselves, to sell their new designs.

1.3. The Aim of Study

Design is one of the most important elements of innovation which is sometimes ruled out. It helps designate how we can interact with products, experience, and selling respectively, effect which products people will buy and what customers are prepared to pay for products.

In this study, we will try to eliminate disadvantages of morphological design by recommended new design methodology.

Morphological approach is one of the most useful methods in the conceptual development stage of the design. This is because the approach of using morphological approach provides solutions to design a product. However, over the last few years, there has been considerable criticism of this design process model (Brooks 2003; 2007; 2010). Some of the weaknesses of the functional decomposition and morphology method of conceptual design on a textbook example were demonstrated. Recently some new methodologies have been introduced in the literature and still being evaluated such as C – K Theory, Parameter Analysis, and Function – Behaviour – Structure Framework.

Recently, a modification has been suggested on the morphological systematic design approach by Sarıgül (2014). The main intention for the modifications was to eliminate the disadvantages of the morphological design. This study will use the core of the modified morphological systematic design approach to evaluate it by using some products such as mechanical fruit press, mechanical pencil and manipulator frame which have morphological charts and design possibilities in appendix.

2. PREVIOUS STUDIES

2.1. Systematic Design

Systematic design refers to a process of design that looks not only at the problem that needs to be overcome, but also at the surrounding environment, and other systems that are linked to the problem. As such, systematic design is the basis for a lot of appropriate technology. Trial and error, and technological evolution are other methods of arriving at a solution appropriate for a system - these are often the basis for vernacular technology. Systematic design, on the other hand, tries to eliminate the time required for these processes, and create a solution in one go. In reality, some combination of approaches is the best - ie. systematic design with prototyping. Systematic design doesn't only apply to technological design, but also to architecture and planning, and broader social system design.

There are some requirements for systematic design approach. These requirements are;

- Be applicable to every type of design activity,
- Foster inventiveness and understanding,
- Be compatible with other disciplines,
- Not rely on chance,
- Facilitate the application of known solutions,
- Be compatible with electronic data processing,
- Be easily taught and learned,
- Reflect the findings of psychology and ergonomics,
- Emphasize the objective evaluation of results (Clemson University).

2.2. Systematic Design Methods

Systematic design methods provide effective design process and owing to this property, the designers may achieve innovative product according to traditional design process. Systematic design methods comprise a few design approaches which are different to each other.

2.2.1. Function Behaviour Structure

The Function Behaviour Structure method (FBS) framework represents designing by a set of processes linking function, behaviour and structure together. The FBS framework is shown in Figure 2.1.

The function (F) of a designed object is defined as its teleology; the behaviour (B) of that object is either derived (Bs) or expected (Be) from the structure, where structure (S) represents the components of an object and their relationships. Therefore, any design utterance or activity fits into one of these six categories, namely, functions (F), expected behaviours (Be), structure behaviours (Bs), structures (S), Descriptions (D), and requirement (R) (Gero, Pourmohamadi and Williams, 2012).

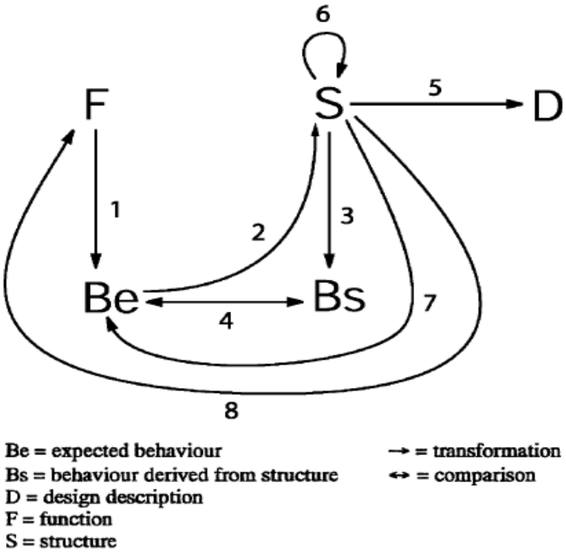


Figure 2.1**.** The FBS framework (Gero and Kannengiesser, 2006).

The FBS frame work consists of eight process. These process are briefly outlined below as;

1. *Formulation*. Transforms the design requirements, expressed in function (F), into behaviour (Be) that is expected to enable this function.
2. *Synthesis*. Transforms the expected behaviour (Be) into a solution structure (S) that is intended to exhibit this desired behaviour.
3. *Analysis* derives the 'actual' behaviour (Bs) from the synthesized structure (S).
4. *Evaluation* compares the behaviour derived from structure (Bs) with the expected behaviour to prepare the decision if the design solution is to be accepted.
5. *Documentation* produces the design description (D) for constructing or manufacturing the product.

6. *Reformulation* type 1 addresses changes in the design state space in terms of structure variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.
7. *Reformulation* type 2 addresses changes in the design state space in terms of behaviour variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.
8. *Reformulation* type 3 addresses changes in the design state space in terms of function variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.

Function Behaviour Structure provides a new foundation for the development of intelligent agent-based design systems and it brings together important concepts of situated agents and the three basic variables. These variables are function, behaviour and structure. This ability to deal also with design concepts like behaviour and function, besides structure, can make situated design agents potentially powerful enough to support the designers in the conceptual steps of designing (Gero and Kannengiesser, 2006).

2.2.2. Science Based Products

Science Based Products (SBP) can be defined as the product concept still requires functional definition and the development scientific research programme about the main phenomena associated with the product. This definition implies two distinctions. According to these distinctions, SBP is different from applying existing research results and a basic science program. If to make these distinctions clear;

- Applied research is usually considered as the application of existing scientific results coming from previous research to the design of some well identified functions.

- Basic science program has usually no clear functional goal. SBPs clearly aim at new product, functional goals exist albeit only partially and in a broad form.

These types of developments show a sequence of important changes that redefine the identity, meaning, knowledge, scope and main actors of projects. However, these changes are neither chaotic, nor random, nor unmanageable in terms of design theory (Hatchual, Le Masson and Weil, 2006).

2.2.3. Concept – Knowledge Theory

Concept – Knowledge (C-K) Theory which proposed by Hutchel in 1996, offers a formal framework that comments present design theories as special cases of a unified model of reasoning. The C–K theory figures out design problems which cannot be solved by using traditional design methodologies. In the article, the researchers had been discussed how C-K theory overcomes the limits of traditional design theories and creativity methods in innovative design situations. A graphical representation of a C-K Design Theory is shown in Figure 2.2.

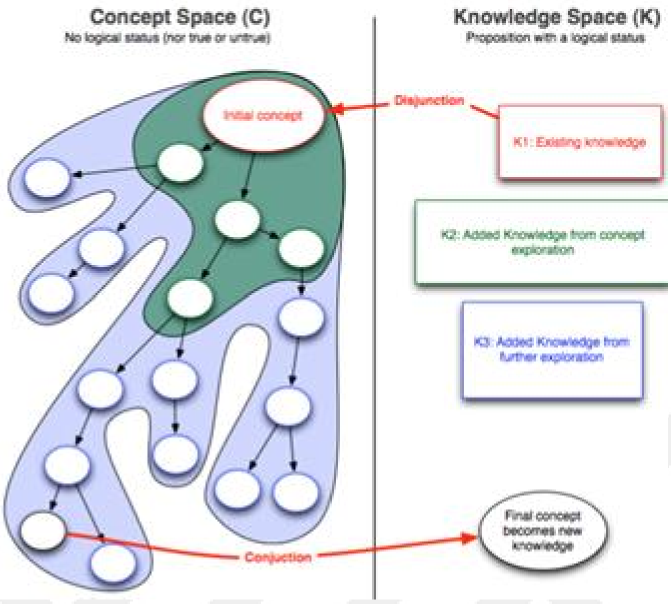


Figure 2.2. A graphical representation of a C-K Design Theory (Hatchuel, Le Masson and Weil, 2004)

C-K design theory can be defined with two spaces. These stages are spaces of concepts “C” and spaces of knowledge “K”. Space K contains all established, or true, propositions, which is all the knowledge available to the designer. Space C contains ‘‘concepts,’’ which are undecidable propositions (neither true nor false) relative to K. Thus the design process is nothing more than the operators that allow these two spaces to expand because each space helping the other to expand. However there are necessarily four different kinds of operators. These are;

- The external ones : C→K, K→C ;
- The internal ones C→C, K→K.

The definition of knowledge design is a set of propositions with a logical status, according to the knowledge available to the designer or the group of designers. The knowledge space describes all objects and truths which are established from the point of view of the designer. After that, K-Space is expandable as new truths may appear in it as an effect of the design process. On the contrary, the structure and properties of the K-Space have a major influence on the process.

The concept stage of C-K theory is defined as a proposition without a logical status in the K-Space. A main finding of C-K theory is that concepts are the necessary departure point of a design process. Design reduces problem-solving without concept. Concepts claim the existence of an unknown object that presents some properties desired by the designer. Concepts can be partitioned or included, but neither searched nor explored. As mentioned before fundamental structure of the design process combines the four types of operators consist of external operators (C→K and K→C) and internal operators (C→C and K→K). These operators generated “Design Square” “Design Square” and shown in Figure 2.3

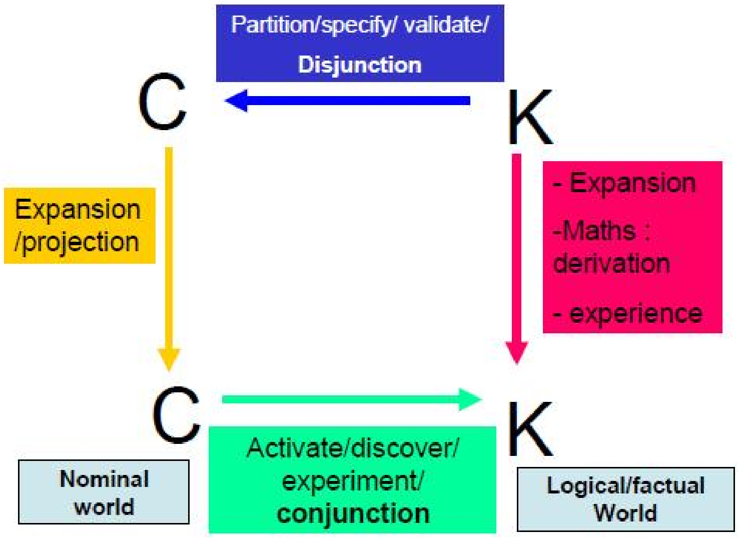


Figure 2.3. The design square (Hatchuel, Le Masson and Weil, 2004)

Briefly the importance of C-K theory is concept & knowledge spaces indicate separately. C-K theory clarifies the generating of design decision by the interaction among two spaces. In design process, properties of knowledge spaces also provide generation of new knowledge. Beginning concept partitions to subsets step by step Process continues until accept it truth by designer and then concept becomes a part of knowledge which calls conjunction.

The problem of this theory is to find one or more solution while design space expanding.

Hutchuel, Le Masson and Weil had been underlined how C-K reasoning models with the same unified framework such conflicting designs situations. With regard to these data, C-K theory also helped to avoid the traps that usual reasoning, be it systematic design, or problem solving approaches, would have induced in such cases (Hatchuel, Le Masson and Weil, 2004).

2.3. Morphological Design

One of the most known systematic design methodology is morphological design which will be focused in the study to compare with a new systematic design approach. Morphological design methodology is a table based on to generate design solutions according to customer requirement. On the left side of the chart, the functions are listed, as for that on the right side, different alternatives which can be used to provide the functions listed are represented in Table 2.1. The design solution creation is accomplished by generating single systems from different mechanisms rowed in the morphological chart. The morphological chart is recommended to generate several innovative designs using different mechanisms for each function for each concept.

The morphological design chart is generally applied in the beginning of notion generation. Analysis of function is used for a beginning point. Keep in mind that morphological design methodology is not suitable for all design problems. The morphological design is successful especially for design problems in the field of engineering design.

To use a morphological design chart, generates individual solution concepts by combining one solution means from each function. The list of possible solutions can quickly grow quite large when additional means and functions are added to the chart. The solution alternatives can be reduced by eliminating impractical concept means. This activity prunes the initial morphological chart. Additionally, impractical combinations of allowable means can also be eliminated from combinatorial consideration reducing the number of resulting design solutions (Richardson, Summers and Mocko, 2011).

Table 2.1. A morphological chart (Richardson, Summers and Mocko, 2011)

Function	Means					
F_1	$M_{1.1}$	$M_{1.2}$	$M_{1.3}$	...	$M_{1.4}$	$M_{1.m}$
F_2	$M_{2.1}$	$M_{2.2}$	$M_{2.3}$	...	$M_{2.4}$	$M_{2.m}$
F_3	$M_{3.1}$	$M_{3.2}$	$M_{3.3}$	...	$M_{3.4}$	$M_{3.m}$
...	...	...	...	...	...	...
F_n	$M_{n.1}$	$M_{n.2}$	$M_{n.3}$	...	$M_{n.4}$	$M_{n.m}$

Morphological design methodology has many advantages and disadvantages as the all of design tools. Advantages of morphological design involve their ability to illustrate unexpected pairings of properties, the potential creation of extraordinary concepts not otherwise considered by the designer, and the capability to represent and explore large regions of the design space. Three specific limitations to morphological charts as design tools are the potential for the number of concepts to grow exponentially making exploration difficult, the reality that not all combinations of means will be feasible solutions to the design problem, and the absence of a set of guidelines to determine a useful way to choose the promising concepts for further evaluation.

The researchers had tried to improve on the representation and exploration of the design by increasing the quality. However, this improvement had been applied through a set of specific guidelines for using with morphological charts. In this manner, the researchers had proved some existing advantages had been enhanced and a current limitation had been specified.

2.4. Morphological Design Applications

Morphological design methodology is one of the most outstanding design methodologies provided to design literature in recent years. Design engineers and researchers have used this methodology for their design process and/or investigations. Some morphological design application examples are given in following sections.

2.4.1. Morphological Design for a Prosthetic Hand

The purpose of the study is to generate a prosthetic hand which includes artificial bone and artificial skin by using morphological design methodology implemented by Dana D. Damian and Konstantinos Dermitzakis (2010) because of conventional engineering design methods is inadequate to fulfil the requirements for generating a prosthetic hand. Artificial bone and artificial skin had been designed by researchers with the help of morphological design methodology. This is a tough target because of human hand is the one of the most complex structure of human body.

At the end of study, the researchers had been provided to remove some undesirable cases such as gross skeletal weight, high volume of artificial bones, and slipperiness of artificial skin which are shown in Figure 2.4 and 2.5. Consequently, the cognitive effort of a user interacting with such a device will be mitigated, allowing for smoother human-robot integration (Damian and Dermitzakis, 2010).

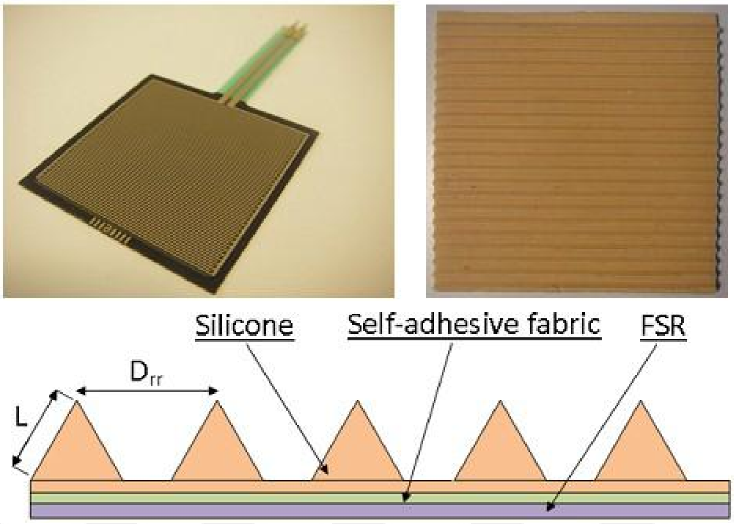


Figure 2.4. Artificial skin of prosthetic hand (Damian and Dermitzakis, 2010)

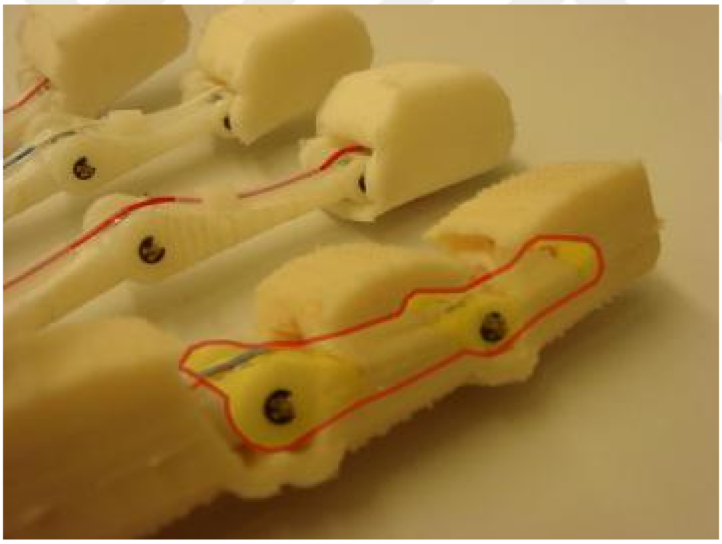


Figure 2.5. Artificial bones of prosthetic hand (Damian and Dermitzakis, 2010)

2.4.2. Morphological Matrix Applied for Manipulator Frame

A research has been carried out by Oskar Ostertaga, Eva Ostertagová and Róbert Hunady (2012), on the design of a manipulator frame using morphological matrix. The purpose of the study was to design a manipulator travel frame with optimum properties. However, some mechanical properties such as stiffness, and strength had been analysed and compared with other manipulator travel frame design. The work flow of researchers consists of three main stages. These stages are analysis of task, frame component selection, and choice of optimum alternative.

The first stage of manipulator travel frame design is about the determination of the properties of the frame. Thus, morphological design methodology had not been used in this stage. On the other hand morphological design methodology had been considered for next two stages. In the second stage, operational principles of the respective solutions are represented in Table 2.2.

Table 2.2. Morphological matrix of the frame choice (Ostertag, Ostertagová and Hunady, 2012).

o. n.	partial function	operational principles			
1	beam cross - section shape	closed 2xU	closed □	open 2xL	open H
2	beam material	structural steel	cast iron	alloy Al	
3	beam fabrication technology	longitudinal weld of 2xU, 2xL rolled rods	rolled	cast	drawn
4	prop cross - section shape	closed 2xU	closed □		
5	prop material	structural steel	cast	alloy Al	
6	prop fabrication technology	longitudinal weld of 2xU rolled rods	cast	drawn	
7	beam and prop connection	by welding	by screws		

The next stage of the study is the choice of optimum alternative. To realize this aim, Table 2.3 shows that minimum reduced stress according to Von Mises, maximum deformation, and weight had been specified.

Table 2.3. Design element characteristics (Ostertag, Ostertagová and Hunady, 2012).

design element	stress acc. to von Mises [MPa]	maximum deformation in dir. x, y, z [mm]	weight [kg]
beam 1	36.2	0.647; −0.648; 0.028	156
beam 2	74.0	1.983; −3.376; 0.086	165
beam 3	36.2	0.640; −0.648; 0.023	142
beam 4	36.1	1.764; −1.784; 0.076	53
beam 5	54.9	1.049; −1.087; 0.035	231

Based on these analysis, the researchers had been decided to choose the frame 1 because of maximum vertical deformation − 0.648 mm and horizontal deformation of 0.647 mm. This type of frame was the most suitable to the stiffness due to reduced horizontal deformation of 0.647 mm. This type of frame was the most suitable to the stiffness specified by the submitter of the task. Maximum stress within mentioned frame reached the value of 36.2 MPa according to von Mises. In this case the theorem of the stiffness was performed at very high degree of safety. Comparable values of the stiffness were reached with the frame 3 (0.640 mm−0.648 mm) however the applied material was more expensive and more demand regarding the connection and from that reason this solution reached the third place. Remaining solutions did not satisfy the criterion of the stiffness. With increased stiffness it would be necessary to affect the dimensions of the beam structure and then the condition of the submitter of the task would be failed. On the other hand the rate of safety was also very much exceeded in this case. (Ostertag, Ostertagová and Hunady, 2012).

2.4.3. Automated Synthesis of Electromechanical Design

The designers had been imagined a different methodology for an ideal design process. In a study carried out by Tolga KURTOĞLU and Matthew CAMPBELL (2009), the researchers designed a thermal mug and wall climber toy by using morphological design methodology.

2.4.3.1. Creation of a Thermal Mug

Their first product which exploits morphological design is thermal mug and its concept variants shown in Table 2.4. The most important property makes different from other mug design is, the users can control and adjust the temperature using an electric motor connected to a battery. After implementation of design process, final product is represented in Figure 2.6 as a sketch.

Table 2.4. Morphological matrix of thermal mug (Kurtoğlu and Campbell, 2009)

Morphological Matrix for Thermal Mug Design				
	Solution 1	**Solution 2**	**Solution 3**	**Solution 4**
import liquid	water tank	hose	cap	fountain machine
store liquid	water tank	bubble	cup	baby bottle
guide liquid	hose	cap	chute	levee
export liquid	water tank	hose	mouth	
stop thermal energy	styrofoam	air pocket		
import electrical energy	plug and cord	lightning rod	generator	thermo-electric device
transfer electrical energy	plug and cord	wire	circuit board	terminal block
store electrical energy	battery	capacitor	electolitic goo	
supply electrical energy	battery	capacitor	electolitic goo	
actuate electrical energy	switch	transistor	timer	temp sensor
transfer electrical energy	plug and cord	wire	circuit board	terminal block
convert electrical energy to thermal energy	thermo-electric device	heating plate	heat exchanger	resistor
transfer thermal energy	metal plate	ceramic disc	water	air
convert electrical energy to rotational energy	motor			
convert rotational energy to pneumatic energy	fan	blower		
import gas	fan housing	hose	straw	car AC
export gas	fan housing	hose	straw	fan blade
import human material	handle	housing	strap	
guide human material	handle	housing	strap	
export human material	handle	housing	strap	
import mechanical energy	housing	cap	handle	
distribute mechanical energy	housing	bottom cap		
export mechanical energy	bottom cover	housing		
import human energy	switch			
convert human energy to control signal	switch			

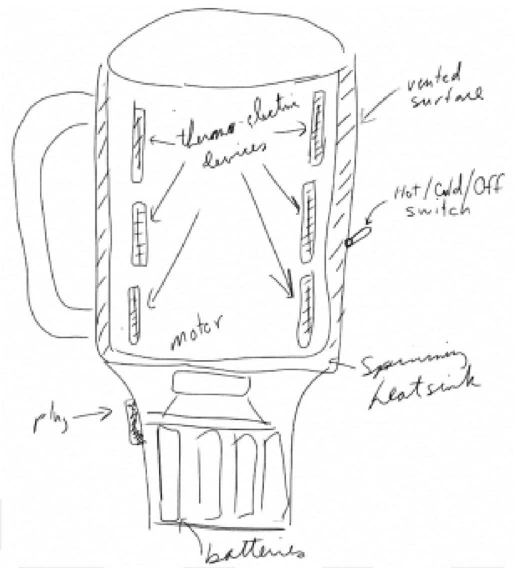


Figure 2.6. Conceptual sketch of thermal mug (Kurtoğlu and Campbell, 2009)

2.4.3.2. Creation of a Wall Climber Toy

In a work performed by Tolga KURTOĞLU and Matthew CAMPBELL (2009), another example is given about morphological design for a wall climber toy. But the researchers had been taken a different task in this stage and they asked to students to design the toy by using morphological design which shown in Table 2.5 and the configuration flow graph or CFG. Configuration flow graphs are typical graph structures represented by a set of nodes (vertices) and arcs (edges) like functional structures. In a CFG, nodes of the graph represent product components, whereas arcs represent flows. For flow naming, the functional basis terminology is adopted, while the components of the graph are named using the standard names of the component basis. At the end of the design process, students had created almost similar concepts. But there were some little differences such as control and activation of devices.

Table 2.5. Morphological matrix of wall climber toy (Kurtoğlu and Campbell, 2009)

Morphological Matrix for the Wall Climber Toy				
	Solution 1	Solution 2	Solution 3	Solution 4
store electrical energy	battery	capacitor		
supply electrical energy	battery	capacitor		
transfer electrical energy	wire	metal plate	electric conducter	
actuate electrical energy	switch	transistor	circuit board	
convert electrical energy to rotational energy	motor			
change rotational energy	gear	pulleys	lever	
transfer rotational energy	driveshaft	belt	link	axle
convert rotational energy to translational energy	wheel	half-tracks	link	
import solid material	gripper	latch	magnet	housing
secure solid material	nut-bolt	guide	magnet	
export solid material	gripper	latch	magnet	housing
import human energy	joystick	knob	handle	
convert human energy to control signal	circuit board	switch	handle	

The students decided to use a "joystick" and a "circuit board controller" to actuate and to manoeuvre the toy, whereas the concept generated only a simple "on/off switch" to address the same functionality which represented in Figure 2.7. In addition to having a high percentage of shared components, the two solutions are also topologically similar. According to this, the connectivity of the components and the energy, material and signal flows through the components are nearly the same in two designs (Kurtoğlu and Campbell, 2009).

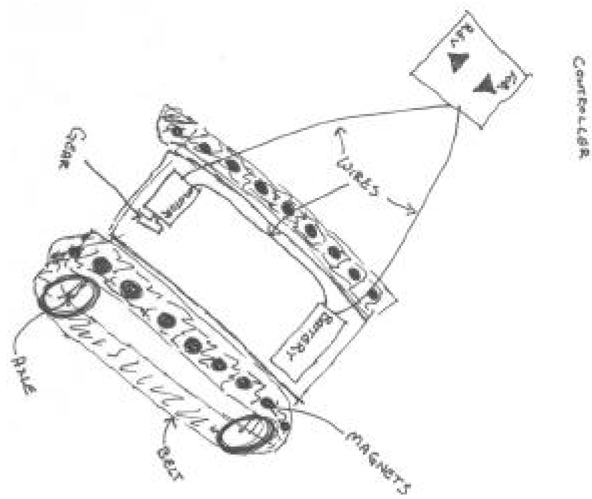


Figure 2.7. Conceptual sketch of wall climber toy (Kurtoğlu and Campbell, 2009)

2.4.4. Design of Machine Vice Based on Morphological Matrix

In a work provided by Prof. Dr. sc. Sadullah Avdiu, MSc. Riad Morina and MSc. Riad Ramadani (2012), morphological design which is one of the creative design methods had been used for machine vice design. Representation of machine vice components shown in Figure 2.8.

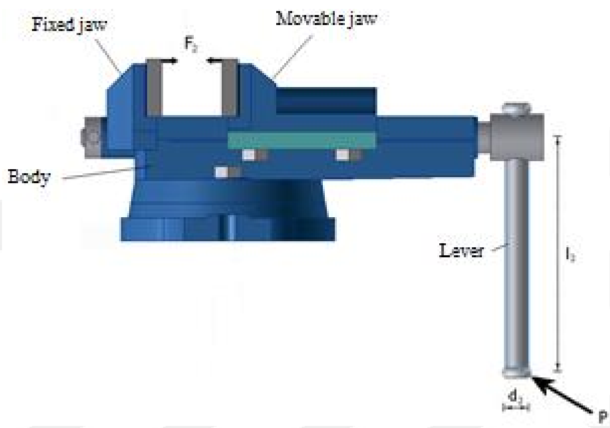


Figure 2.8. Machine vice components (Avdiu, Morina and Ramadani, 2012)

First stage of design process study is to generate a morphological chart. Generation of variants had been done with take advantage of morphological matrix, which shown in Table 2.6. While generating morphological chart, the researchers analysed many kind of variants. In general, from the presentation of some of the possible variants the authors identified some essential features of a machine vice. These features should be common to all variants, although may have different ways to perform the function.

Table 2.6. Variant generation based on morphological matrix (Avdiu, Morina and Ramadani, 2012)

Variants / *Partial functions*	VARIANT A	VARIANT B		
Basement	Fixed basement	Movable basement	Portable basement	
Operation	Manual	Electric	Pneumatic	
Body function	Fixed body	Swivel body		
Locking of clamping force	Self-locking	Hand forced	Hydraulic	Pneumatic
Setting of workpiece	With hand	Robotized		
Removal of workpiece	With hand	Robotized		
Surface apparance	Only anti-corrosive	Green	Blue	Red
Jaw plate	Plastics	Metal	Wood	Rubber
Operator place	On legs	Sitting	Remote control	Lying

After that, to determine best product properties, the researchers exploited VDI guidelines technique. The VDI guideline proposes a simple approach, based on a five-point scale to score the alternatives which represented in Table 2.7. In order to apply the guidelines from VDI 2225, the alternative matrix and criteria matrix have to be converted into the VDI scale and form. However, variant analysis had represented in Table 2.8 based on VDI guidelines (Avdiu, Morina and Ramadani, 2012).

Table 2.7. Score scale of VDI technique (Avdiu, Morina and Ramadani, 2012)

Score scale	
Description	Score
Very good	4
Good	3
Satisfactory	2
Acceptable	1
Unsatisfactory	0

Table 2.8. Analysis of variant based on VDI guidelines (Avdiu, Morina and Ramadani, 2012)

Variants / *Partial functions*	VARIANT A	VARIANT B		
Basement	Fixed basement	Movable basement	Portable basement	
Operation	Manual	Electric	Pneumatic	
Body function	Fixed body	Swivel body		
Locking of clamping force	Self-locking	Hand forced	Hydraulic	Pneumatic
Setting of workpiece	With hand	Robotized		
Removal of workpiece	With hand	Robotized		
Surface apparence	Only anti-corrosive	Green	Blue	Red
Jaw plate	Plastics	Metal	Wood	Rubber
Operator place	On legs	Sitting	Remote control	Lying

Based on the evaluation of variants under the Table 2.9, it is concluded that Variant A with the combination of possible options presented, meets the conditions to produce (Borille and Gomes, 2011).

Table 2.9. Analysis of variants based on cost and function (Avdiu, Morina and Ramadani, 2012)

According to VDI 2225 Guidelines the five-points system will be used: 0=Unsatisfactory, 1=Acceptable, 2=Satisfactory, 3=Good, 4=Very good.								
Partial functions	**Variant A**	Cost	Function	Points	**Variant B**	Cost	Function	Points
Basement	Portable	x	x	x	Fixed	x	x	x
Operation	Manual	x	x	x	Manual	x	x	x
Body function	Swivel base	1x2=2	2x4=8	2+8=10	Fixed base	1x3=3	2x2=4	3+4=7
Locking	Self-locking	x	x	x	Self-locking	x	x	x
Setting of workpiece	With hand	x	x	x	With hand	x	x	x
Removal of workpiece	With hand	x	x	x	With hand	x	x	x
Surface apparence	Anticorrosive+ Blue	1x3=3	2x4=8	3+8=11	Green	1x4=4	2x1=2	4+2=6
Jaw's plate	Metal	1x4=4	2x4=8	4+8=12	Plastic	1x3=3	2x1=2	3+2=5
Operator place	On legs	x	x	x	On legs	x	x	x
			Total Points	33			**Total Points**	18

Because of morphological matrix method are determined different variants and, their evaluation is done after which a decision was taken to select the optimal variant. Method of evaluation and decision making had supported in design method, and resolve it the optimal with minimum error.

2.4.5. Mobile Phone Concept Generation

A mobile phone concept by using morphological chart was generated by Zaharis et al. (2011). Mobile phone is widely used and important device at the present time. To develop an innovative mobile phone concept, the researchers had been decided to use morphological design methodology. They had been detected the possible functions for generating mobile phone concept. These functions include holding, storage, dialling, display, power supply, signal reception, signal processing, sound output, extra features. For example in the case of holding possible solutions can be stopwatch-type grip, attached to clothing, gun grip. The morphological chart had been created by using these functions and options which remedy to functions and shown in Table 2.10.

Table 2.10. Morphological chart example for a mobile phone (Zaharis. Kourtesis, Bibikas and Inzesiloglou, 2011).

Morphological chart for a mobile phone				
Function	Options			
Holding	Stopwatch style	Calculator style	not held	
Storage	Pin badge	on sleeve	on belt	in pocket
Entering no	Keypad	Voice	Bar code	
Display	LED	LCD	None	
Power supply	Mains	Battery	Solar	
Signal reception	Internal aerial	External aerial	Cable aerial	
Sound output	Speaker	Earphone		
Sound input	Internal microphone	External microphone		
Extra features	Calculator	Memory bank	Alarm	Games

Researches due to the morphological chart, a solution had been a mobile phone that it is not held, had been stored as a pin badge, a keypad had been used to dial the number, with no display, power by a battery, with an internal aerial, an internal microphone and with a large memory bank (Zaharis. Kourtesis, Bibikas and Inzesiloglou, 2011).

2.4.6. Morphological Analysis in Production System Design

Morphological analysis was also used in Production System Design. In a study which describes the morphological analysis in the design of production process, there are two main parts explained by Eva Ostertagová, Jozef Kovác, Oskar Ostertag, and Peter Malegab (2012). The first part of the study is about to deal with morphological analysis procedure. The second part is about generating variants examples of existing type of production system.

Morphological analysis procedure used in the study consists of five basic steps. These steps are;

- Identification of the basic functions of building components and subsystems of defined production system.
- Creation the list of all possible forms, in which can building elements of the production system occur. Each variant of the proposal consists of a certain number building components and subsystems.
- Identification of all possible combinations of building elements and subsystems.
- Identification of all applicable variants in practice
- The final reduction of possible combinations.

In morphological chart, the aim of column is to show the title and structure of particular variants. As well as rows of morphological chart emphasizes the serial number of variant, the summary of building elements or subsystems and their possible realizations (forms), the row expressing the acceptability of variant, rows of the particular evaluation criteria, row of final evaluation and row for marking the selected variants.

At the present, innovative products relate to production system design based on philosophy of the variant, interactive problem solving, their optimization and automation. These factors are vital in decision making stage based on the application of modern methods and tools. In characterized solution, these methods had been integrated with the main project activities and their information security in a comprehensive unit (Ostertag, Ostertagová, Kovac and Malega, 2012).

2.4.7. Application of Morphological Analysis for Selection & Storage

In a work generated by Eva Ostertagová, Jozef Kováč, and Peter Malega (2011), morphological design method were used to figure out complex design problems such as material flow and storage allocation. With regard to researchers, problem solving process consists of four elementary phases, namely: definition of the problem, analysis, synthesis and processing of the solutions. Using of morphological approaches in automated designing of production systems allows;

- Radically innovative solutions,
- Combination of all theoretically possible solutions. It eliminates disruptive impact lack of information, rigidity in thinking (conservatism) and prepossessions,
- Systematically classification of documents as a source of ideas about unconventional technical, technological and economic solutions,
- Widely applicability (not only in solving technical, but also in social problems),
- To create a tree of significance used in values analysis, or to apply the method of multi-criteria evaluation of alternative solutions.

Combination options, under the classification characters, allow creating multiple variants of structures of material flow and storage (reservoirs) allocation to production system. At next phase, the morphological chart had been generated according to material flow and storage allocation variants.

This study indicates that, morphological design methodology is not only a useful tool to solve design problems. As well as this methodology is particularly valuable in the early stages of conceptual solutions. To the elements that investigator knows from his personal experience, even accessing also elements of the known and proven solutions, so the number of elements and thus the incentives for associative thinking is still expanding. To this, process researchers can exploit further morphological methods (Ostergova, Kovac and Malega, 2011).

2.5. Efforts to Improve Morphological Design Methodology

At this part of study, some disadvantages will be represented which backed up with investigations applied to mechanical product design. The researchers had modified the morphological design methodology to eliminate these disadvantages.

2.5.1. Conceptual Design Using a Synergistically Compatible Morphological Matrix

In the study, Richard Weber and Sridhar Condoor (1998) had discussed some disadvantages of morphological matrix which is a methodology that can improve the effectiveness of the concept generation phase of the design process. In the task, the air vest had selected to design with fourteen subtasks. Morphological matrix of this design which is shown in Table 2.11 creates 4.782.969 different concepts. In order to address these difficulties, they had extended the morphological matrix methodology by including the Theory of Coupling.

Table 2.11. Morphological matrix for the air vest design task (Weber and Condoor, 1998)

Task	Solution #1	Solution #2	Solution #3
Vest	Signboard	Standard Jacket	Hooded Jacket
Vest straps	Belt buckle	Seat belt	Snaps Tensioners
Air supply	Pyrotechnic Explosion	Compressed Gas	Foaming Agent
Indicator	Pop Top	Dial Gage	Green Eye
Trigger Mechanism	Tether	Accelerometer + Electronics	Combined Option (1+2)
Lock out protection	Min Tension	Min Tension + Speed Removal	Electronic Lockout
Air delivery manifold	Polymer Tubing	Metal Tubing	Sewn in Fabric Ducts
One-way valves	"Joker" Valve	Spring Loaded Valve	Diaphragm
Air bladders	Seamless Balloon	Rigid Collapsible	Treated Sewn Fabric

Air pressure containment layer	Sewn Fabric	Mesh	Straps
Air chamber protection layer	Fabric	Mesh	Rigid Collapsible Interlocking Panels
Folding arrangement	Serpentine	Concertina	Rolled
Air chamber outer shell	Detaching Overshell	Tear Away	Attached To Chamber
Vision window	Vision Window	Inflated Clear Shield	Rigid Face Visor

The "Air Vest" designers had some difficulties executing an effective morphological matrix. These difficulties are;

- The team had not use a systematic methodology to identify the relevant functions,
- Their matrix had not distinguish the primary functions from the secondary functions,
- The functions had identified in configurational terms and therefore, are not at a fundamental level of abstraction, and
- The independence and compatibility of all functions had not well tested.

These problems were addressed by incorporating the hierarchical nature of the design process and "The Theory of Coupling" into the morphological matrix methodology.

The Theory of Coupling is a known phenomenon in design. It can be defined as the conflicting interdependence of two or more functions. Due to the interdependence, a coupled design requires a designer to trade performance on different functions. As a consequence, unless eliminated, it invariably results in a sub-optimal solution. According to the theory, any design can be viewed as a system that interacts with its environment by the means of inputs and outputs. These inputs and outputs separate five categories such as energy, material, information, generalized forces (includes moments) and generalized displacements (includes rotations).

Concept generation phase by using the morphological matrix methodology described various steps and illustrates them by the air vest example. These steps are;

- Identify independent primary functions: In this step identifying independent primary transmission paths and primary functions.
- Create solutions for primary functions: The designer must create solutions for each primary function in this step. The solutions for the air vest example had summarized in Table 2.12.

Table 2.12. Air Vest primary morphological matrix (Weber and Condoor, 1998)

Transmission Path	Functions	Solution Alternatives		
		Solution #1	Solution #2	Solution #3
Force	Attenuate the impact force	Gas	Liquid	Solid
Attenuation Agent (Material)	Store agent	Compressed state	Individual chemical elements state	
	Transmit agent	In-chamber (no transmission required)	Piping	
	Contain agent	Single chamber	Multiple chamber	
Accident Information	Detect accident	Accelerometer + Electronics	Snap-off tether	
	Provide activation signal	Mechanical signal	Electrical signal	Chemical signal
Visual Information to the Rider	Provide visibility	Rigid window	Flexible window	

- Create primary morphological matrix: The designer has to create the primary morphological matrix in this step.

- Choose a compatible synergistic solution: This step entails choosing individual solutions that are compatible and also, synergistic.
- Identify lower-level functions: Once a system-level design is established, then the designer must explore lower –level functions.
- Create lower-level solutions: The designer must create solutions for these lower-level functions
- Create lower-level morphological matrices: An important difference between the primary and lower-level morphological matrices is that lower-level matrices are performed for each primary solution. For instance, Table 2.13 shows the lower-level morphological matrix for the multiple chamber solution.

Table 2.13. Lower-level morphological matrix (Weber and Condoor, 1998)

Lower-level Functions	Solution #1	Solution #2	Solution #3
Contain pressure	Fabric	Plastic layer	
Provide mechanical integrity	Fabric	Mesh	Rigid collapsible interlocked panels
Provide inflatability	Concertina	Serpentine	Plastic deformation

- Choose a compatible synergistic solution: The designer chooses a compatible solution that meets the interface constraints and exploits the synergy.
- Evaluation: After creating a compatible solution incorporating the secondary functions, the designer must decide whether the solution is developed to sufficient detail.

The results from the case study presented in the research support the usefulness of the Morphological Matrix Methodology for creating innovative solutions to meet design needs. However, it had shown that unless the matrix is organized in a hierarchical structure, it would lead to incompatible and synergistically impaired solutions. Proposed in the research is a hierarchical procedure to develop design solutions from a morphological matrix, which are compatible and have a higher probability of synergy. (Weber and Condoor, 1998).

2.5.2. The Morphological Matrix: Tool for the Development of Innovative Design Solutions

In the study, Mario Fargnoli, Edoardo Rovida and Riccardo Troisi (2006) had determined some disadvantages of morphological design methodology. Some of these disadvantages are;

- Giving a few indications concerning the feasibility of the solutions carried out,
- Decreasing the effectiveness of the problem solving activities,
- Requirement of a team of experts in order to increase the possibility of obtaining innovative solutions.

Because of these reasons, the development of procedure aimed at improving the use of morphological matrix had been performed, augmenting the probability to achieve innovative solutions using the traditional design approach, whose use certainly reduce the occurrence of mistakes and neglecting significant aspects of the project.

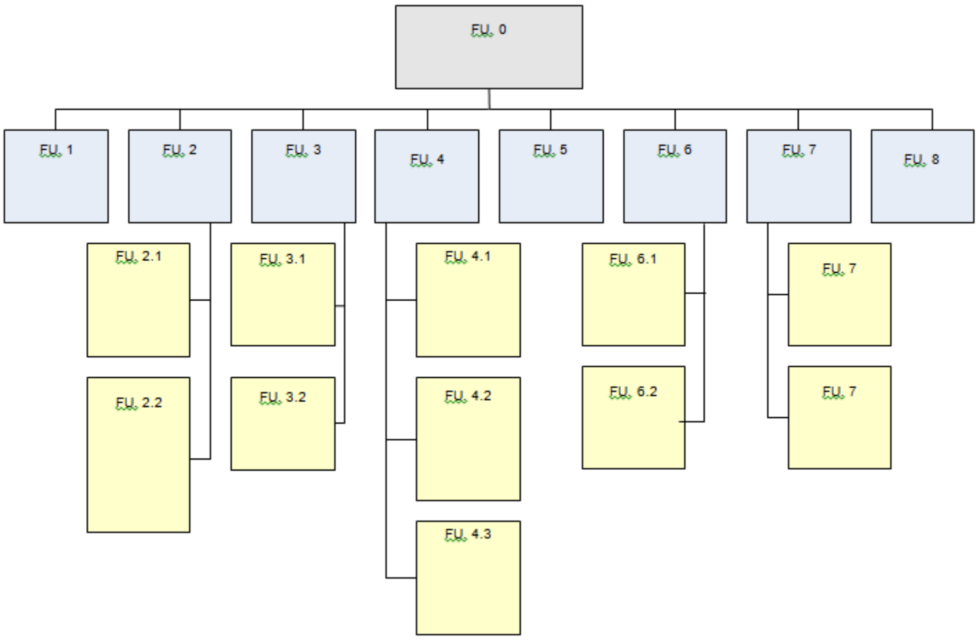
The study had focused on the analysis of the earliest design stages of the design process, and in particular on the so called "conceptual design" stage, with the goal of integrating the traditional approach based on the use of a systematic and methodical approach, together with effective design tools aimed at increasing the probability to find innovative solutions, such as triz and creax which is triz based method.

Modified morphological design methodology consists of seven stages. These stages are;

- The general function: The general function is performed by the machine can be expressed as a transformation from an initial to a terminal state.
- Physical Phenomenon: The general function can be realized by the utilization of a general physical phenomenon.
- Choice of the “Best” Phenomenon: The output of the second step consists in a set of phenomena that can perform the given function; the optimal phenomenon can be chosen.
- Analysis of the General Function F: Such a function, in general, can be analysed dividing it in different “component functions”.
- Individuation of the principles for each component function Pi: Each component function Fi can be realized by using different physical (or, in general, natural) principles.
- Choice of the “best” principle for each component function: The choice of the “best” principle can be made in relation to the behaviour of the principle.
- Synthesis of the selected principles (constructive solutions): this output can be used as a source of new solutions

The first step consisted in defining the structure of the function that the system has to perform. In Table 2.14 the “function tree” of the hierarchical relationships among the main function and the sub- functions of the system, is shown. (Fargnoli, Rovida and Troisi, 2006).

Table 2.14. Analysis of the system function using the Hierarchical Tree (Fargnoli, Rovida and Troisi, 2006).



The following step consisted in the development of the morphological matrix. The further step consisted in finding new solutions using the creax method. Actually, the “function tree” resulted in being very useful in order to have a complete perspective of the system and implement in a more efficient way the morphological matrix.

More in detail, in Table 2.15 an excerpt of the traditional Morphological Matrix is represented: for each component function, a set of known constructive solutions is proposed is represented; in Table 2.16, instead, represents the same part but in a schematic version, more useful and faster to be understood than the previous one (Fargnoli, Rovida and Troisi, 2006).

Table 2.15. Traditional morphological matrix (Fargnoli, Rovida and Troisi, 2006)

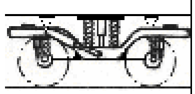
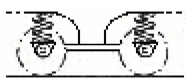
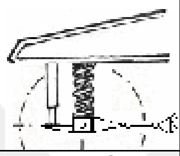
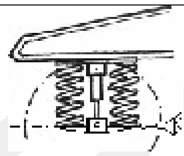
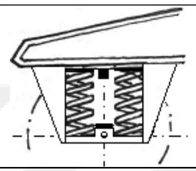
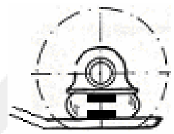
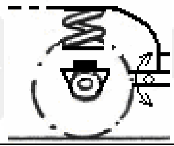
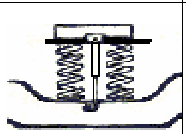
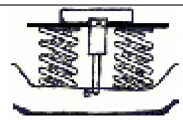
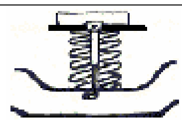
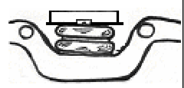
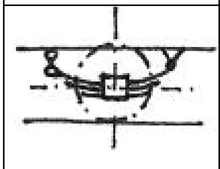
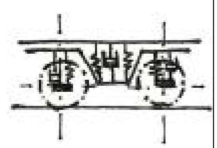
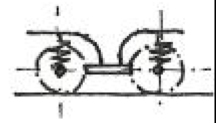
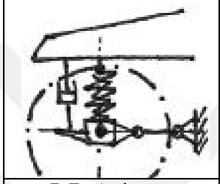
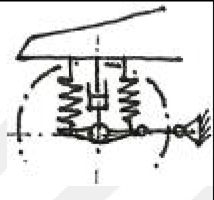
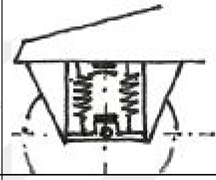
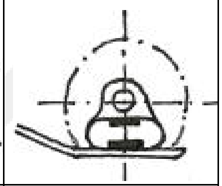
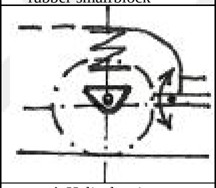
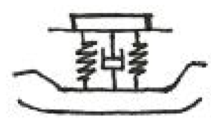
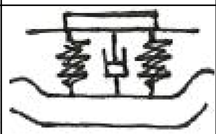
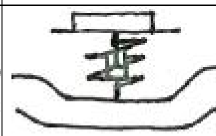
N°	FUNCTION	ACTUATORS			
1	To connect the wheel-set and the carriage	A Carriage spring	B Bogie	C Bogie with single-stage suspension	
					
2.1	To allow the primary suspensions simultaneously working)	A Coaxial helical springs + shock absorber	B Helical springs working in parallel + shock absorber	C Helica springs working in parallel + shock absorber	D Pressure spring + rubber small block
					
		E Torsion bar +helical spring + rubber small block	F Absent	G Absent	
			Single-stage suspension with bogie	Bogie is absent	
4.2	To reduce oscillations between the bogie and the carriage frame (secondary)	A Helical springs working in parallel + shock absorber	B Coaxial groups of helical springs working in parallel + shock absorber	C Coaxial helical springs + shock absorber	D Pressure springs (torpress)
					
		F Absent	G Absent		
		Single-stage suspension with bogie	Bogie is absent		

Table 2.16. Modified morphological matrix (Fargnoli, Rovida and Troisi, 2006)

N°	FUNCTION	ACTUATORS			
1	To connect the wheel-set and the carriage	A Carriage spring	B Bogie	C Bogie with single- stage suspension	
					
2.1	To allow the primary suspensions simultaneously work	A Coaxial helical springs + shock absorber	B Helical springs working in parallel + shock absorber	C Helical springs working in parallel + shock absorber	D Pressure spring + rubber small block
					
		E Torsion bar +helical spring + rubber small block	F Absent	G Absent	
			Single-stage suspension with bogie	Bogie is absent	
4.2	To reduce oscillations between the bogie and the carriage frame (secondary)	A Helical springs working in parallel + shock absorber	B Coaxial groups of helical springs working in parallel + shock absorber	C Coaxial helical springs + shock absorber	D Pressure springs (torpress)
					
		F Absent	G Absent		
		Single-stage suspension with bogie	Bogie is absent		

2.6. The Novelty in Morphological Design Methodology

At this part of research, the novelty of modified morphological design methodologies which were mentioned in section 2.5 will be mentioned.

In section 2.5.1, an integral step in the new procedure is “The Theory of Coupling” based on the transmission of energy, material, information, generalized forces and generalized displacements. Based on the procedure, it was shown how an incompatible morphological matrix could be restructured into a series of compatible matrices utilizing a hierarchy of design functions and solutions. By way of this modification, morphological matrix became easier by decreasing the solution alternatives (Weber and Condoor, 1998).

In section 2.5.2, the approach proposed is based on the use of a modified Morphological Matrix, that allows designers an easier and at the same time a more effective generation and assessment of the design concepts by integration of the design strategy supported by design methods and techniques. This modified version of morphological design had allowed providing good result concerning development of the conceptual design phase. An approach had brought to light the importance of the use of the “Morphological Matrix” for the concept generation and assessment. Indeed, such a tool had to be considered not only as an example of solutions for each component function, but also as a “heuristic method”, useful to reach innovative solutions, helped designers in taking into account all the available solutions (Fargnoli, Rovida and Troisi, 2006).

2.7. The Comparison of Morphological Design and Parametric Analysis

The issue of the study about a comparison between two systematic design methodology which are parametric analysis and morphological design. The aim of Kroll (2012) is not to criticize the quality of morphological design methodology. The reason of this study is to prove some weaknesses of the morphological design methodology. Morphological design concept is a guide for bilge pump design given in Figure 2.9. This concept design uses wave energy to remove water from boat. Linear spring stores the energy to wave which is energy source. Thus, linear spring transfers the energy to reciprocating pump. As a conceptual design, morphological matrix cause to some weakness in bilge pump. These weaknesses are provided by Kroll (2012);

- Developing a solution-independent function structure is difficult and does not integrate well with the natural flow of activities during design,
- The breadth-first manner of treating sub functions and their corresponding sub concepts may distract the designer's attention and prevent focusing on the dominant issues,
- The conceptual designs generated usually lack quantification and therefore have not been proven viable,
- There is no prescribed concept development process for transforming the collection of individual sub concepts into a coherent conceptual design.

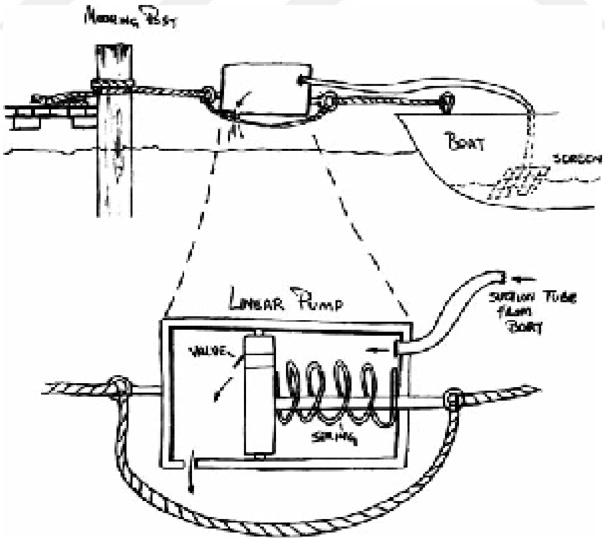


Figure 2.9. Bilge pump concept by leading morphological design (Kroll,2012)

Parameter analysis is further and improved development of conceptual design methodology than morphological design. This methodology puts in the centre repeatedly identifying dominant conceptual-level issues and relationships, implementing these concepts as configurations, and continuously evaluating the evolving design. The researchers evaluate many possible energy creation methods such as solar, wave, wind, etc. and then decided to use wind energy for comparison with morphological design.

At the end of conceptual design process with regard to parameter analysis, new bilge pump design is shown in Figure 2.10.

If functional decomposition and morphology were used for this conceptual design, the record kept would indicate that this concept was based on capturing wind energy with a propeller, transmitting it with gears and a crankshaft to a reciprocating pump that employs flapper valves to control the flow direction, tubes for moving the bilge water, and a screen to filter them.

In contrast, a concept development process with parameter analysis, might also show that a propeller was chosen after the option of ‘‘air cups’’ was evaluated quantitatively and shown to result in too large a structure; that the propeller and pump were roughly sized to provide the power necessary for the required flow rate and pumping head; that the use of a horizontal wind turbine has not been considered by the designer at all, something that might have eliminated the use of the bevel gears; and that the choice of a reciprocating pump was not satisfactorily justified, so a rotary pump might have been a better choice overlooked by the designer. This added wealth of information is clearly very beneficial when examining a design such as in Figure 2.10 for the purposes of understanding and reusing its rationale.

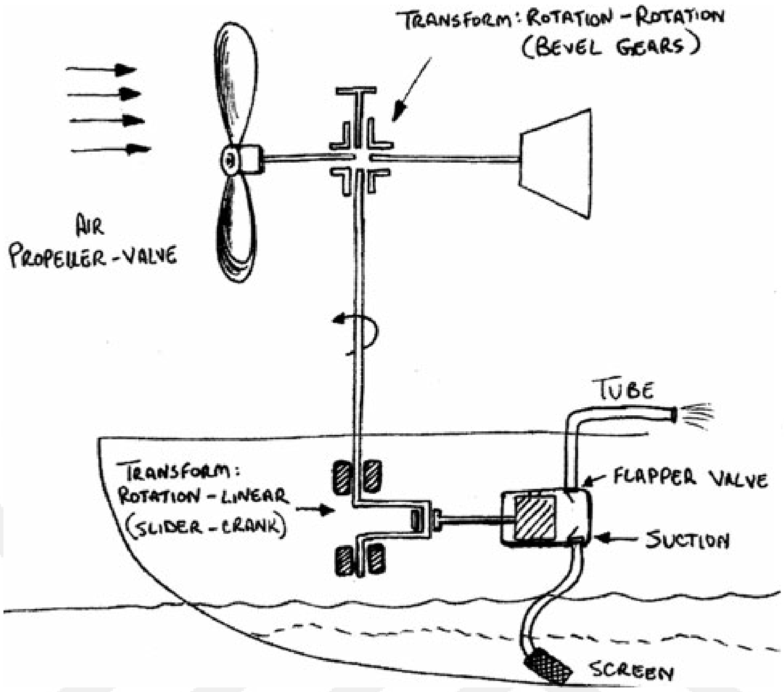


Figure 2.10. Bilge pump concept by leading parameter analysis (Kroll, 2012)

As systematic design's way of doing conceptual design, functional decomposition and morphology is easy to teach and learn, so many contemporary design textbooks have adopted it. However, some of the drawbacks of the method as outlined in the study point at the need to revise the perception of the best methods for teaching and practicing design. In addition to this, parameter analysis supports a much deeper thought process to discover new, creative concepts, which in turn drive the exploration of new knowledge. It therefore constitutes an alternative for both teaching and practicing innovative design (Kroll, 2012).

2.8. The Weakness of Morphological Design Methodology

Morphological design method has some limitations as in all prescience design methodology. If it is necessary to ensample some of the disadvantages of morphological design method are that real-world scenarios do not treat rationally.

For the most part, a simplified model will break down when the contribution of the 'trivial' components becomes significant. As well as, importantly, the behaviour of many components will be governed by the states of, and their relations with, other components ones that may be seen to be minor before the analysis.

Morphological analysis, in other respects, does not drop any of the components from the system itself, but works backwards from the output towards the system internals. The interactions and relations get to play their parts in morphological design and their effects are accounted for in the analysis.

If the limitations of the morphological design examine in detail, the designers may encounter some disadvantages like many conceptual design methods, the development of morphological chart requires critical judgment thus the possibility of human error is present. The studies which improved morphological design were mentioned by case study in 2.5. If the underlying thought processes are not insightful, the outcomes of this method will be weak. At times, it may be too structured, inhibiting free, creative thinking. Additively morphological analysis may yield too many possibilities shown in tables in appendix. For this reason, time consumption may increase significantly.

Starting from this point, a new approach to systematic design will be work on to eliminate these disadvantages of morphological design methodology. This study will use the core of the modified morphological systematic design approach to evaluate it.

3. MATERIAL AND METHOD

3.1. Material

In this study, we evaluate the success of the new approach to systematic product design in product design that is suggested by Sarigül (2014) by comparing it with morphological design. The new approach to the systematic product design suggests a modification for morphological design because of a disadvantage which generates too many solutions, some which may not even be logical; indeed some results are stated to be “bizarre” (Brooks 2007). Therefore, the main intention for the modifications was to eliminate the disadvantage of the morphological design. Three different and simple example products were chosen as samples for the evaluation of the methodology. These products are manipulator frame, mechanical pencil and mechanical fruit press. The most important reason of choosing of them is all functions of these products are mechanical in their functions, thus all properties of the samples could be equally identified.

This study will use the core of the new approach to systematic product design to evaluate it. Evaluations of the method will be carried on the selected simple products in the following sections.

3.2. Method

The study will use two product/machine design methods with the intention of evaluating the suggested one. One is the morphological design methodology and the other one is the new approach to the systematic product design methodology that is suggested recently in a part of a PhD study (Sarıgül, 2014). Both of the methods are based on the functional decomposition and morphology and the main function of the artefact that is targeted is decomposed into finer and finer sub functions. However, some steps are different in the new one.

The three examples that are manipulator frame, mechanical pencil and mechanical fruit press were selected for the evaluations in this work. These examples are going to be designed using the both of the design methodologies with the intention of evaluating the new approach to systematic product design method.

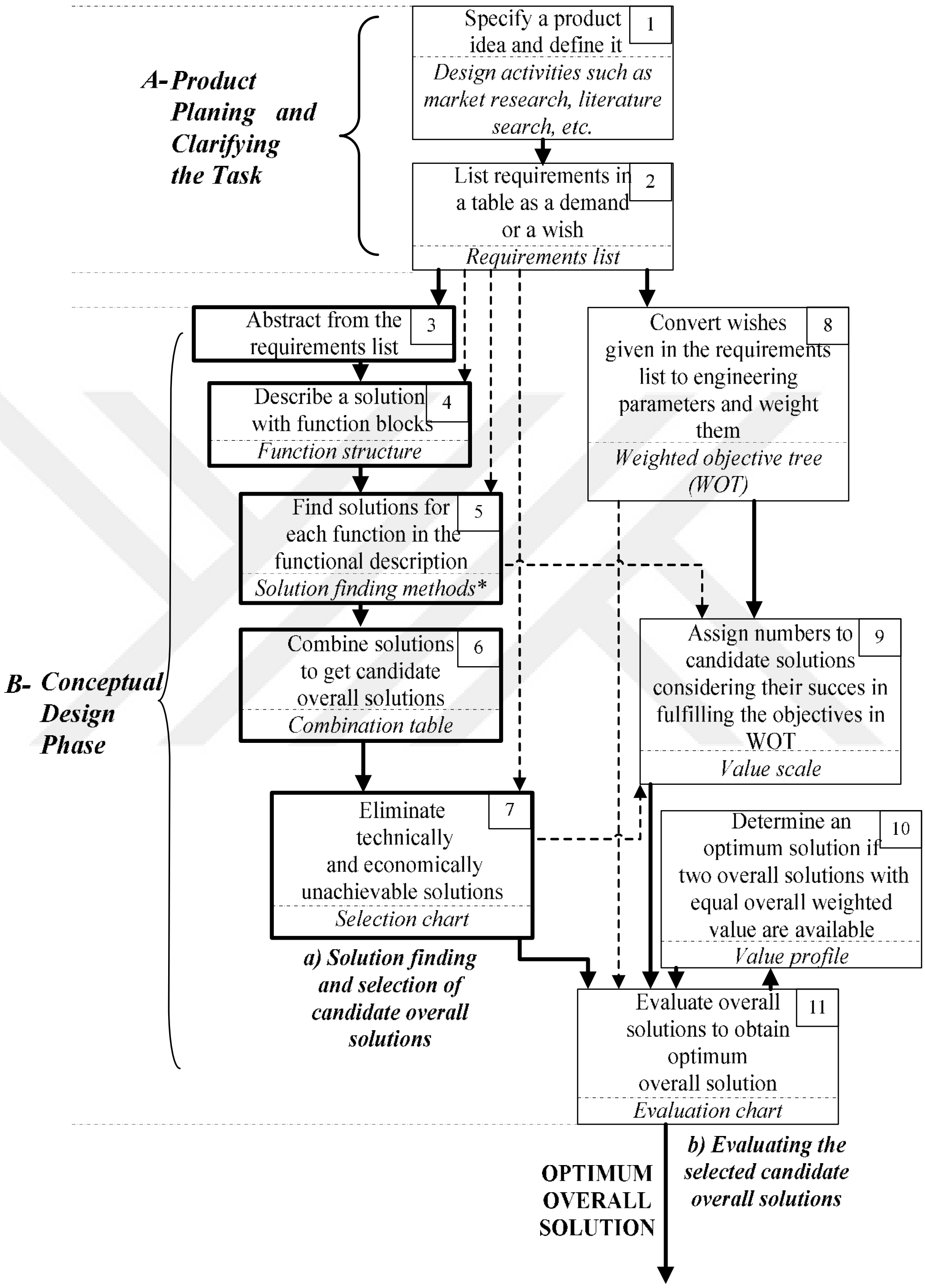
Briefly, the design results of the example products will be used to evaluate the both of the design methods and highlight the advantages of the new one if there is any.

3.2.1. Morphological Design

The morphological design methodology approach is attributed to Fritz Zwicky. Zwicky applied this methodology to many different areas as the classification of astrophysical objects, the development of jet and rocket propulsion systems, and the legal aspects of space travel and colonization. He founded the Society for Morphological Research and advanced the "morphological approach" for some 30 years, between the 1940's until his death in 1974 (Ritchey, 1998).

This method related to a morphological chart which calls design matrix (Table) as well and really only provides for the stages of presenting and evaluating the alternative ideas. To use the morphological chart for this purpose it is of prime importance that the designer has carefully established the specification; to employ the morphological matrix without first doing so could result in obvious chaos. The process flowchart of morphological design methodology is shown in Figure 3.1. It consists of two phases such as ***product planning and clarifying the task (A)*** and ***conceptual design (B).*** These two phases contain total of 11 steps.

The arrows with continuous lines in Figure 3.1 indicate the direction of design steps which must be followed during the design, whereas the arrows with the dotted lines indicate flow direction of data to be referred during the related design step. Design steps (3-11) of the product/machine design methodology are separated into two sub-sections. Sub-section (a) named “solution finding and selection” of candidate overall solutions contains five steps (3 to 7) whereas sub-section (b) named as “Evaluating selected solutions”, where the candidate overall solutions are selected, contains four steps (8 to 11).



(*) indicates solution finding methods such as TRIZ, asit, concept fun and Goldenberg's creativity template.

Figure 3.1. The flowchart of morphological design methodology (Sarıgül, 2014)

Step 5 of Figure 3.1 requires the use of morphological matrix. The matrix of morphological chart comprises of a Table of functions and solution means for each function. Normal convention is to list the functions in a column in the left hand side of the Table, and list the solutions to right of each function (Smith, Richardson, Summers and Mocko, 2012).

To illustrate the use of the morphological matrix, consider the design of a mechanical pencil. The design parameters resulting from the specification would include:

- Body
- Grip type
- Cone cap
- Eraser type

A morphological chart showing these parameters and some possible ways or means (possible solutions) of satisfying them are shown in Table 3.1.

Table 3.1. The morphological chart for mechanical pencil

Alternatives / **Function**	**1**	**2**	**3**
Body			
Grip Type			
Cone Cap			
Eraser			

There are many advantages and disadvantages about the morphological design methodology. Some of the advantages of morphological design are to involve their ability to illustrate unexpected pairings of properties, the potential creation of extraordinary concepts not otherwise considered by the designer, and the capability to represent and explore large regions of the design space. Besides these advantages, there is specific limitation of morphological charts. The most important disadvantage of morphological design methodology is the vast number of solutions provided for design problems. Total solutions of morphological design methodology are calculated by multiplying of solution number of each function with solution numbers of all functions. For example; even a simple product which contains 5 functions with 5 solutions for each function, morphological design methodology generates (5x5x5x5x5=3125) 3125 solutions. The reality that not all combinations of means will be feasible solutions to the design problem, and the absence of a set of guidelines to determine a useful way to choose the promising concepts for further evaluation creates major difficulties for designers.

The core of the morphological design method for the conceptual design stage is given in Figure 3.2.

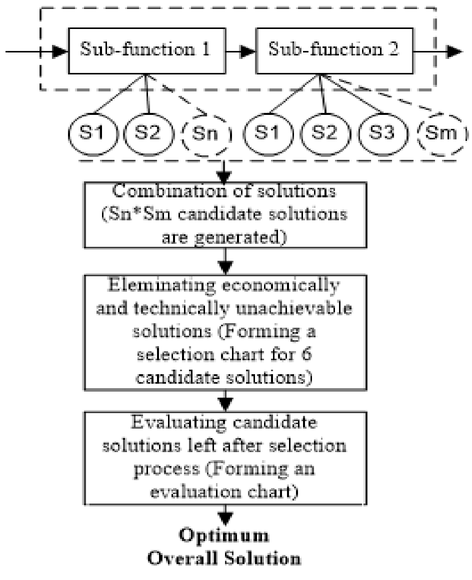


Figure 3.2. Design steps of morphological design method for the conceptual design stage (Sarıgül, 2014)

The procedure provided in Figure 3.1 uses number of tools at each step that are given under the box of each step. These are function structure, solution finding methods, combination table, selection chart, weighted objective tree (WOT), value scale, value profile and evaluation chart. It is applied to the design of three selected samples product ideas in the next chapter.

3.2.2. A New Approach to the Systematic Product Design

Thanks to many advantages, a systematic design methodology is useful for designers while generating innovative design. A systematic design depends upon functional decomposition and morphological approach for concept generation. There are some disadvantages to use morphological approach. Most important disadvantage of morphological approach is to produce too much design alternatives. Evaluation of these design alternatives have caused the designers to make time consuming activities during the design. Recently, a modification has been suggested on the morphological systematic design approach by Sarıgül (2014). The main intention for the modifications was to eliminate the disadvantages of the morphological design.

New design methodology that is given in Figure 3.2 suggests some modifications to morphological design approach given in Figure 3.1. In addition to this, it is benefiting from requirement list, VDI guidelines, selection chart, and weighted objective tree. The following sections explain the role of each in the new approach to the systematic design method.

If Figure 3.3 and Figure 3.1 are compared, the difference can be seen. The developed product design methodology differs from morphological *"systematic product design methodology"* provided by Dieter and Schmidt (2012) at step 2 of the phase A (*"Product planning and clarifying the task")* where the dominating function of a product is determined as shown in Figure 3.2.

The conceptual design phase (B) was also formulated to suit it for the systematic design of a product. Design steps (4-14) of new product design methodology are separated into two sub-sections. Sub-section (a) named defining function, finding solutions and selection, contains four steps (4 to 7) whereas sub-section (b) named as “Evaluation and comparison processes” contains six steps (8 to 14).

In addition to this, the developed methodology is supported by a number of new and modified design tools which consider dominating function. The details of the systematic new product design model with its tools are discussed in the following sections using an implementation example. And the available results of new products are used as a reference to prove it (Sarıgül, 2014).

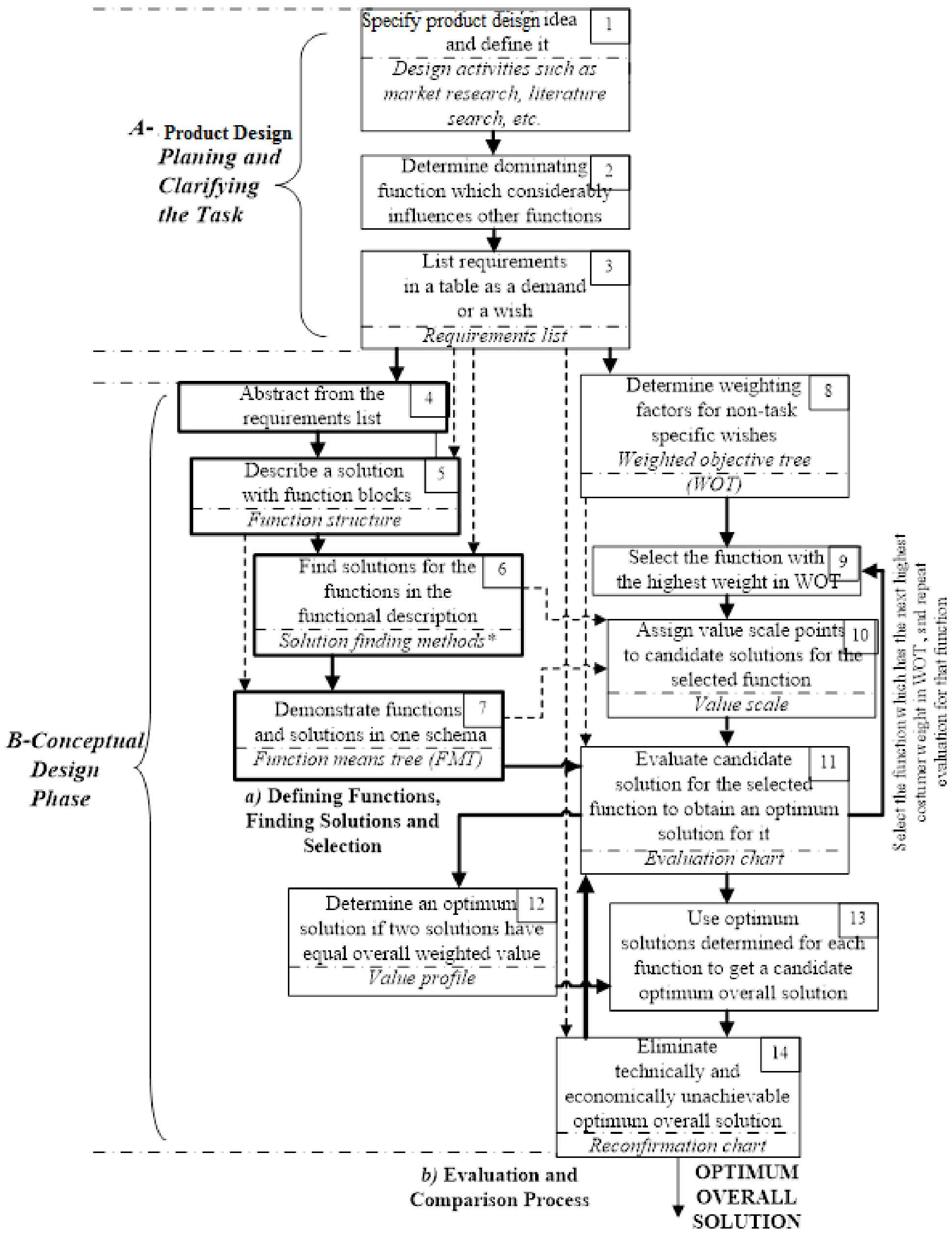


Figure 3.3. The new approach to the systematic product design methodology (Sarıgül, 2014)

Core Design steps of new approach to the systematic design method for the conceptual design stage is given in Figure 3.4.

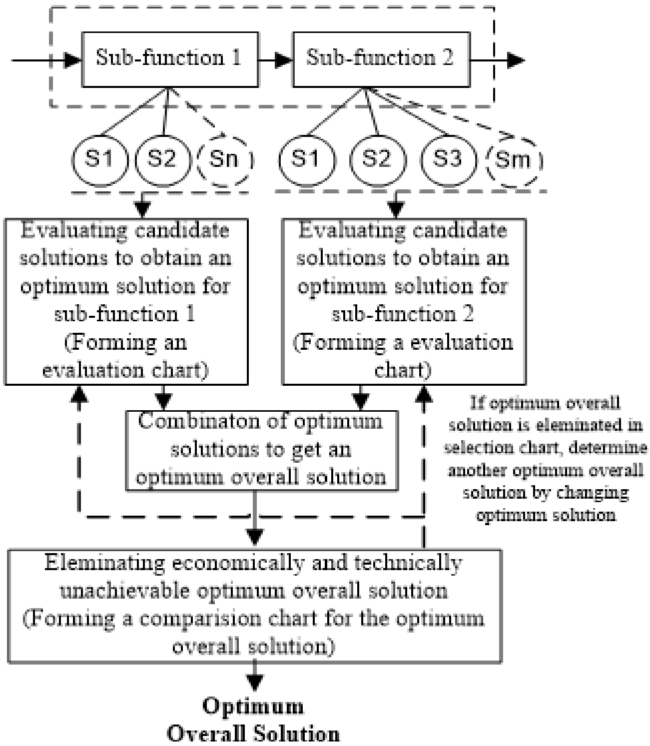


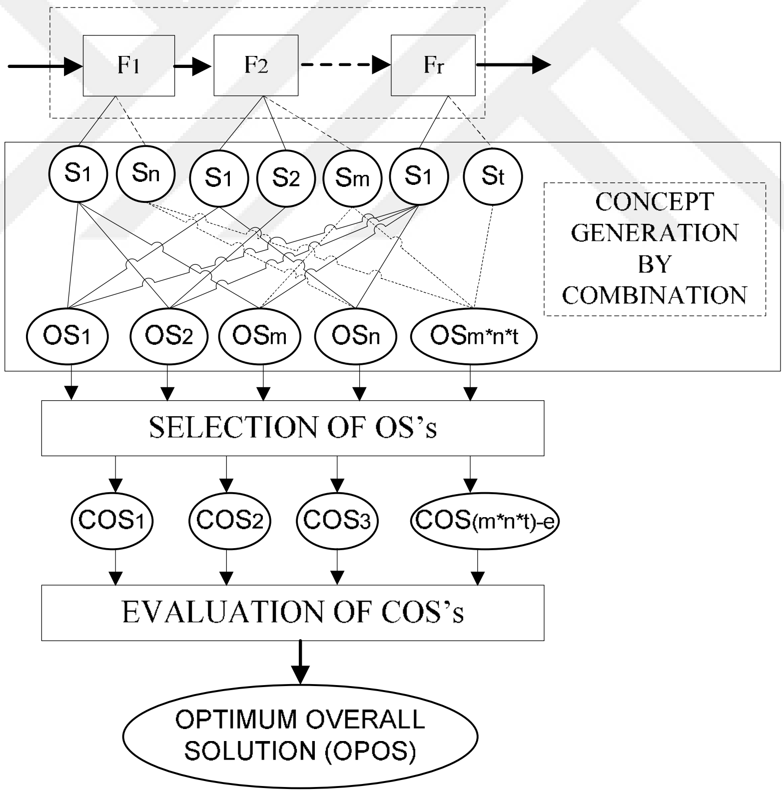
Figure 3.4. Core Design steps of new approach to the systematic design method for the conceptual design stage (Sarıgül, 2014)

This study investigates the possibility of the new approach to systematic product design approach to obtain a better systematic design approach for generating products with minimum effort. As can be seen in the Figure 3.4 above, the new approach to systematic product design provides less design alternatives to reach best product design. The main reason of less design alternatives is the designer evaluates the functions of product individually. Thus, design process takes less time according to morphological design.

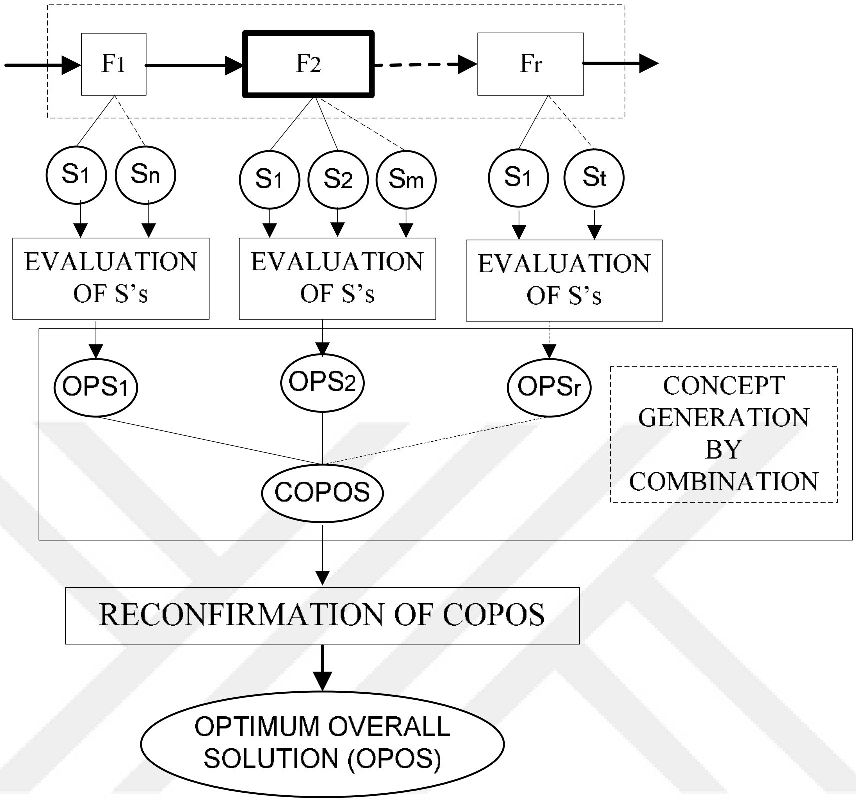
Firstly, the concept development phases of the three selected products (mechanical pencil, manipulator frame and mechanical fruit press) are carried out using morphological approach in the next chapter. This will show the deficiencies of the morphological approach. Then, the conceptual design phases of the same products are carried out using the new approach to the systematic method. This will then demonstrate the efficiency of the new approach to the systematic method.

3.2.3. Comparisons between Morphological Design and New Design Approach

Figure 3.5 below shows the difference between the morphological and the new approach to the systematic design methodologies for the comparison purposes.



(a)



(b)

Figure 3.5. Comparison of (a) the systematic product and (b) the developed product design models

The comparison, given in Figure 3.5, shows that how the new model is used to generate initial core concepts. The new model identifies the "dominating function" at the very early stage and the solution for each function is obtained separately. Then the concept generation takes place after the combination of optimum solution (OPS) obtained with the evaluation of solutions of each function. In Figure 3.5 (a) since all functions are treated equally, dimensions of boxes of F_1, F_2, etc. are shown as being equal to each other, whereas in Figure 3.5 (b) since dominated function are evaluated firstly and then the other functions are evaluated according to their relative importance, dimensions of boxes of F_1, F_2, etc. are represented by varying sizes in order to demonstrate their relative importance. In

Figure 3.5 (b) F_2 is enclosed by **thick lines** as an indication of its being dominating function. Briefly, considering the dominating function, and changing the application order of the selection and the evaluation steps generate an initial core concept (candidate optimum overall solution - COPOS) that attempts to deal with the main and most difficult issue of the design. As opposed to functional decomposition and morphology's treatment, now there is only one COPOS. Consequently, the designer's attention is not distracted by all the sub functions that are independent and discrete as opposed to the rational systematic design model.

Finally, the COPOS is subjected to reconfirming process to obtain optimum overall solution (OPOS). The details of this step are explained at the subsections of section 4 (see step 14).

In addition to this, the developed methodology is supported by a number of new and modified design tools which consider dominating function. The details of the systematic product design model with its tools are discussed in the following sections using three sample product ideas. And the available results of three products are used as a reference to prove it.

3.3. Tools of the Methods

When the designers implement any methods either morphological or new approach to the systematic design, they should follow the steps provided and use some tools at each step as the names of the tools at each step are provided in Figure 3.1 and 3.3. These tools were explained in below. These steps are describable by processual so some of these tools are not considered realizing methods.

3.3.1. Requirement List with Demands & Wishes

A requirements list including data is to be obtained about the new product. A costumer request is vital importance in this stage of new product design methodology, thus compounds are determined for each requirement using design activities such as market research, literature search, etc. However there is a main difference between the requirement list of morphological and the new approach to the systematic product design methods. This difference is about wishes. For morphological method, sum of the ratio of wishes parameters have to be 100%. Contrary to morphological method, in new approach to the systematic design method, sum of the ratio of wishes parameters have to be 100% for each parts of technical properties.

The requirements list shown in Table 3.2 consists of demands and wishes with their costumer weights in parenthesis beside them. The requirements which call demands or wishes, in the requirements list can be differentiated also as task-specific or not task-specific. Task-specific requirement is only accomplished by a tool or function, whereas a non-task-specific requirement is used to qualify and quantify features of an existing tool or function.

Table 3.2. Requirement list with customer demands & wishes a) for morphological design, b) for new approach to the systematic design method

a)

	The requirements list for mechanical pencil		
	D: Demand W: Wish	Requirements	
	D (100%)	Indispensable customer request for product	
	W (10%)	Wish of customer for product	
	W (90%)	**<u>Technical Properties:</u>**	
		Body	
	W (40%)	Wish of customer	
	D (100%)	Indispensable customer request	
	W (15%)	**Grip Type**	
	W (30%)	Wish of customer	
	W (70%)	Wish of customer	
	W (25%)	**Con Cap**	
	W (60%)	Wish of customer	
	W (40%)	Wish of customer	
		Eraser	
	W (20%)	Wish of customer	

b)

	The requirements list of new product design		
	D: Demand W: Wish	Requirements	
	D (100%)	Indispensable customer request	
	D (100%)	Indispensable customer request	
		<u>Technical Properties:</u>	
		Part 1	
	W (45%)	Wish of customer	
	W (55%)	Wish of customer	
		Part 2	
	W (20%)	Wish of customer	
	W (45%)	Wish of customer	
	W (35%)	Wish of customer	
		Part 3	
	W (40%)	Wish of customer	
	W (40%)	Wish of customer	
	W (20%)	Wish of customer	
		Part 4	
	W (60%)	Wish of customer	
	W (40%)	Wish of customer	

The requirements list will be base document in later design steps. A requirements list is formed for mechanical pencil, mechanical fruit press and manipulator frame separately in the following sections.

3.3.2. Creation Function Structure and Finding Solutions

These two steps are the same for both of morphological and the new approach to the systematic product design methods. Firstly, the designers should describe the solutions, and then find solutions for all function.

3.3.3. The Weighted Objective Tree

The objective of the weighted objective tree methodology is to compare the utility values of different design alternatives, on the basis of performance of the design alternatives. Differently from morphological method, the designers determine weighting factors for specific wishes before the selection chart evaluation.

To generate a weighted objective tree which is shown in Figure 3.6, the designers specify the primary objective of the new design product based upon the customer requirement. This objective is decomposed into secondary requirements or objectives. This continues to lower levels of detail for all requirements. To illustrate the relative importance of each of the sub-objectives, weights can be assigned to the branches. In this manner, the final relative weights for the objectives at the leaves may be calculated. This aids the designer in determining where to spend effort in the design process. In this study, the weighted objective tree method has applied separately for all parts of conceptual designs after determination of requirement list (Summers, 2008). A weighted objective tree is formed to weight the non-task specific wishes in the requirements list. As an example, in conceptual design of a mechanical pencil, a weighted objective tree was built based on the requirements list and it is given in Figure 3.6 (Sarıgül, 2014).

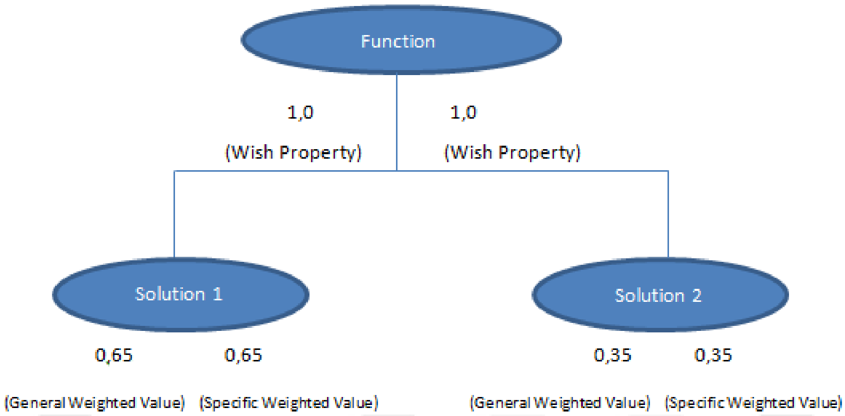


Figure 3.6. Weighted objective tree

In briefly, the weighted objective tree method is used to model the hierarchical nature of the requirements or objectives, of design requirements. The specified weighted value is calculated by multiplying wish property and general weighted value. This tool is used primarily in the early stages of design in requirement definition and clarification, though it should be revisited to ensure that the design team is kept on task

3.3.4. VDI Guideline 2225 Evaluation Technique

In order to describe the ability of each candidate solution to fulfil the related non-task specific wish, using one of evaluation technique which calls VDI guideline 2225. A selection procedure presented by Pahl et. al. (2006) is based on the VDI 2225 (1998), a guideline instruction edited by the Association of German Engineers (VDI). This guideline proposes a simple approach, based on a five-point scale to score the alternatives. The scale and the evaluation Table are presented in Table 3.3.

Table 3.3. Value scale for VDI guideline 2225 evaluation technique

Guideline VDI 2225	
Points	Meaning
0	unsatisfactory
1	just tolerable
2	adequate
3	good
4	very good

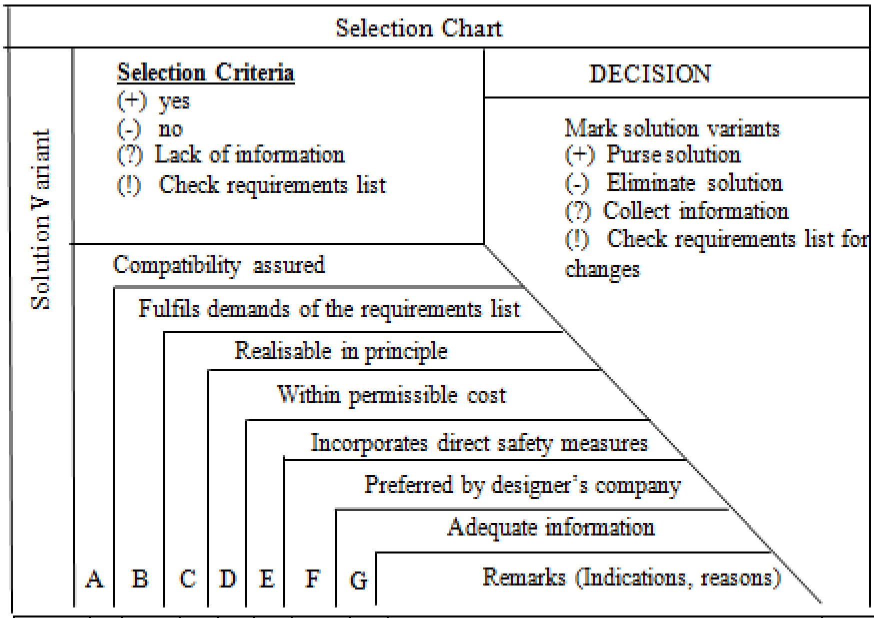
In order to apply the guidelines from VDI 2225, the alternative matrix and criteria matrix have to be converted into the VDI scale and form. The Association of German Engineers (VDI – Verein Deutscher Engenieure) edits regularly guidelines to support engineers to their habitual activities. These guidelines often support or even become standards (Borille and Gomes, 2011).

In the study of Avdiu et al. (2012), VDI guidelines 2225 evaluation technique had been considered to determine best design alternative for machine vice.

3.3.5. The Selection Chart

Unlike morphological method, in this step of the design process applies after the WOT evaluation in the new approach of systematic product design methodology. High scoring candidate of WOT evaluation method among overall solutions have been determined by applying the selection chart method. As for that morphological method, selection chart generated for all solutions. In this design step, design of a new product is evaluated technically and unachievable solutions among candidate overall solutions are eliminated by the help of selection chart which is shown in Table 3.4. The difference of selection chart from the weighted objective tree is that the designers consider only demand parameters in the requirement list for the selection chart, but for weighted objective tree, the designers consider only wishes parameters in the requirement list.

Table 3.4. The selection chart



	A	B	C	D	E	F	G	Remarks	
V_1	+	+	-	+	+	+	?		
V_2	+	+	+	+	+	+	?		

In this design step, in order to make product design process much safer for designer. As can be seen in Table 3.4, seven notifications for the selection criteria which are “Compatibility assured” , “Fulfils demands of the requirement list”, “Realisable in principle”, “Within permissible cost”, “Incorporates direct safety measures”, “Preferred by designer’s company” and “Adequate information” are introduced into available selection chart. These notifications warns designer to be careful against the special design case according to demands which are mentioned above, before eliminating candidate overall solution when a minus sign is given to one of first four of these notifications in the selection chart because these are the most important parameters in selection chart. If the high scoring solution is eliminated because of minus sign, selection chart evaluation implements for second high scoring solution in WOT for related function.

3.4. The Application of New Design Approach

In this study, both of the design methodologies were applied to the selected sample products.

The procedure of new design approach which is suggested to believe as alternative for morphological design has some differences. A new product idea requirements relating to product idea and costumer weights for these requirements are outcomes of this design step. The requirements list which is the first step of new design approach procedure including data obtained. However, in order to illustrate the weaknesses of systematic product design methodology much more obviously, only basic functions (assembly parts) of a new design of a product are given in Table 3.2 which is generated for this step. Requirements for these functions are deliberately selected among many requirements in order to be able to demonstrate weaknesses of systematic product design methodology much more clearly. The requirements list consists of demands and wishes with their costumer weights in parenthesis beside them.

All of the demand parameter has 100 %. Because demand means is sine qua non of customer request. However, wish parameter means that reason for preference for customers, and the totally ratio of all of wish parameters have to be 100 %. Alternatives design solutions for all functions are determined after obtaining the customers’ requests.

The next design step is to evaluate of wishes. In this design step, a weighted objective tree is formed to weight the non-task specific wishes in the requirements list. The weighted objective tree was built based on the requirements list. In this study, weighted objective tree method has applied separately for all parts of a mechanical pencil, manipulator frame and mechanical fruit press.

An evaluation chart is generated separately for all parts of product design in this step, and functions for wishes listed in left column while the alternatives solution listed at the upper row. WOT scheme and evaluation chart of morphological design method are shown in Figure 3.7 and Table 3.5 respectively.

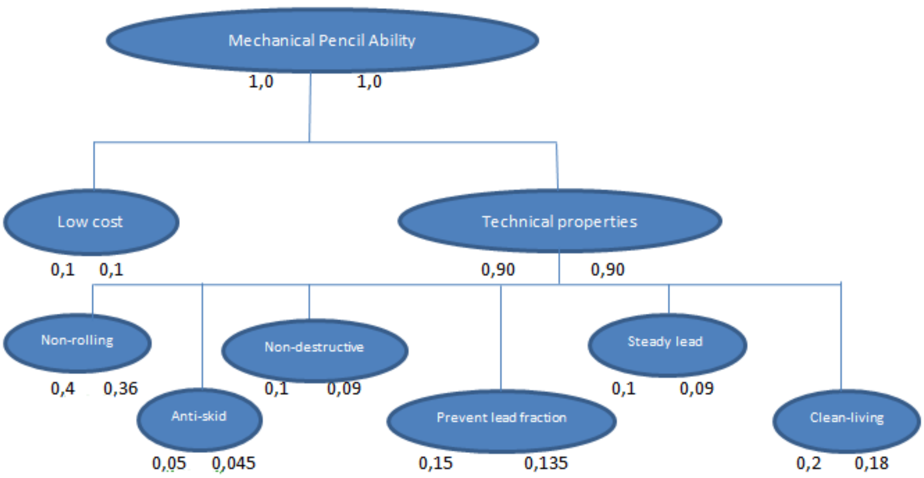


Figure 3.7. WOT scheme of grip type of mechanical pencil for morphological design

Table 3.5. The evaluation chart of grip type of mechanical pencil for morphological design

			V_3		V_6		V_{12}		V_{18}		V_{24}	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.1	3	0.3	3	0.3	2	0.2	2	0.2	2	0.2
2	Non-rolling	0.36	4	1.44	4	1.44	2	0.72	2	0.72	2	0.72
3	Anti-skid	0.045	4	0.18	4	0.18	4	0.18	2	0.09	3	0.135
4	Non-destructive	0.09	4	0.36	3	0.27	4	0.36	3	0.27	4	0.36
5	Prevent lead fraction	0.135	4	0.54	3	0.405	4	0.54	3	0.405	3	0.405
6	Steady lead	0.09	4	0.36	4	0.36	4	0.36	4	0.36	4	0.36
7	Clean-living	0.18	3	0.54	3	0.54	3	0.54	3	0.54	4	0.72
		$\sum Wt.=1$		$\sum OWV_3=$ 3.72		$\sum OWV_6=$ 3.495		$\sum OWV_{12}=$ 2.9		$\sum OWV_{18}=$ 2.585		$\sum OWV_{24}=$ 2.9

WOT scheme and evaluation chart of new approach to systematic design method are shown in Figure 3.8 and Table 3.6 respectively.

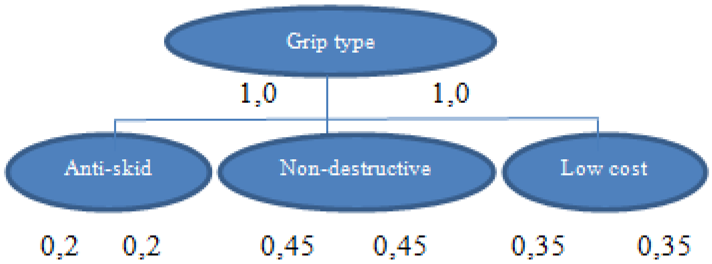


Figure 3.8. WOT scheme of grip type of mechanical pencil for new approach to systematic product design

Table 3.6. The evaluation chart of grip type of mechanical pencil for new approach to systematic product design

			Rubber		Groove		Rubber & Groove	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Anti-skid	0.2	3	0.6	4	0.8	3	0.6
2	Non-destructive	0.45	3	1.35	3	1.35	4	1.8
3	Low cost	0.35	4	1.40	3	1.05	2	0.7
		$\sum$Wt.=1		**$\sum OWV_1$= 3.35**		$\sum OWV_2$= 3.2		$\sum OWV_3$= 3.1

After that, alternative solutions are evaluated by applying analysis techniques either using use-value analysis or VDI guideline 2225. Finally, evaluation results of all parts are sum up. Thus, the best solution determined for new product design.

The last step of new design approach is to generate selection chart for demands to make the final decision by the designers. There are seven parameters to evaluate in selection chart. The designers determine which parameters have to exist for product. If the solution does not fulfil the demand in the requirements list, a minus sign is given for the selection criteria, thus the product with minus sign is eliminated by designers. If the product fulfils demands of the requirements list a plus sign is given for the selection criteria. By definition of the new approach to systematic product design methodology as mentioned above in Figure 3.3 for right product choice, there is no minus sign among parameters have to exist for products which are specified by designers.

After the practicing the morphological and new approach to the systematic design methodologies to all products, highest scoring design products for both of the design methods are compared. In order to accept that the new approach to the systematic design methodology is more practical and remove disadvantage of morphological design methodology, both of high scoring product designs must be same. If the product design is not the same, this study will have shown that the new approach to systematic product design method is not taking over morphological one.

4. RESULTS AND DISCUSSION

As mentioned in the previous chapter, a new design approach has been proposed for systematic design of mechanical parts of sample products. In this section, the processes of morphological design and a new approach to the systematic product design are explained in detail. Catia V5R2015 was used as 3D design platform for designing mechanical parts of sample products. The results of the implementation of morphological design and a new approach to the systematic product design and its phases are compared and explained step by step in the following sections for sample products of mechanical fruit press, manipulator frame, and mechanical pencil. All of the manufacturability of selected alternatives was analysed and evaluated.

4.1. Application of Morphological Design to Sample Products

In the first step of the study, sample products which are mechanical fruit press, mechanical pencil and manipulator frame were designed by morphological design. The design process of these products will be explained step by step in the next titles considering the methodology provided in Figure.3.1 of Chapter 3, and disadvantages of the morphological method will be signified. We had mention at previous chapter the original condition of requirement list, morphological matrix, selection chart, WOT schema, and evaluation chart in Table 3.2 (a), Table 3.1, Table 3.4, Figure 3.7, and Table 3.5 respectively.

4.1.1. Application of Morphological Design to Mechanical Fruit Press

There are nine main expectations for mechanical fruit press by customers. These, which are obtained by simple market research, are low cost, low weight, corrosion resistance, less sliding, comfortable handling, easily removable, good pressing ability, sieve, and ease of use based on the market research as shown in Table 4.1 (see Table 3.2 (a) in Chapter 3). There are several methods that were implemented for the study of market such as interview with mechanical fruit press users, searching user's opinion on internet, and etc. We detected five operational necessities to fulfil customers' requirements. These parameters are body, pressing, support, sieving, and carafe.

Table 4.1. Customer requirements list for the mechanical fruit press

	The requirements list for mechanical fruit press		
	D: Demand W: Wish	Requirements	
	D (100%)	Corrosion Resistance	
	D (100%)	Cost of product < 20€	
	W (%3)	Low cost	
	W (%5)	Low weight	
	W (92%)	**<u>Technical Properties:</u>**	
		Body	
	W (25%)	Less sliding	
		Pressing	
	W (15%)	Good press ability	
		Support	
	W (13%)	Comfortable handling	
	W (4%)	Easily removable	
		Sieving	
	W (23%)	Low diameter hole	
	D (100%)	Hole dimeter < 10 mm	
		Carafe	
	W (20%)	Ease of use	

In the view of this information, we have described some solution alternatives to fulfil customer requirements. After the description of solution alternatives, the morphological matrix table which is the characteristic feature of morphological design (see Table 3.1 in Chapter 3) is created as shown in Table 4.2.

Table 4.2. Morphological matrix table for the mechanical fruit press

Alternatives / **Function**	**1**	**2**	**3**	**4**
Body	Free standing monoblock	Free standing pronged	Lockable monoblock	Lockable pronged
Pressing	Upside and Monoblock	Side & Horizontal Handle	Upside and Pronged	Side & Vertical Handle
Support	Handle			
Sieving	Sieve			
Carafe	Carafe with sieve	Carafe without sieve		

The disadvantage of conventional morphological matrix appears after creation of morphological matrix table. This disadvantage is, many possible combinations and different solutions can be constituted. In mechanical fruit press study, there are 32 (4x4x1x1x2) different design alternatives which are shown in Table A-6 show up when alternatives for each function is considered. All of these alternatives were evaluated by using selection chart to determine whether it fulfils demands or not as shown in Table 4.3 (see Table 3.4 in Chapter 3), and selected alternatives shown as bold. This situation caused a loss of time. Because the designers have to determine all design alternatives individually to find the best design solution. Inherently, some of these 32 different alternatives may not be practical solutions, or it may only be inadequate.

Table 4.3. Selection chart for evaluation of demands parameters of mechanical fruit press

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	DECISION
V_1	+	+	+	+	+	+	?		
V_2	-	+	+	+	?	+	+		
V_3	+	+	+	+	+	?	+		
V_4	+	+	+	+	-	?	+		
V_5	-	+	+	+	?	-	?		
V_6	+	+	+	-	+	+	?		
V_7	-	+	+	+	-	+	?		
V_8	+	+	+	-	-	+	?		
V_9	+	-	+	+	?	+	?		
V_{10}	+	+	+	-	+	-	+		
V_{11}	-	+	-	+	+	+	?		
V_{12}	+	+	+	-	+	?	+		
V_{13}	+	-	+	+	?	-	?		
V_{14}	+	-	+	+	-	-	+		
V_{15}	+	+	-	-	-	?	?		
V_{16}	+	-	+	+	+	-	?		
V_{17}	+	+	-	+	-	-	+		
V_{18}	+	+	-	+	-	-	?		
V_{19}	-	+	+	+	-	?	+		
V_{20}	+	+	-	+	-	-	?		
V_{21}	+	-	+	+	?	+	?		
V_{22}	+	-	+	+	+	-	?		
V_{23}	-	+	+	+	+	-	?		
V_{24}	+	+	+	-	+	-	+		
V_{25}	+	+	+	-	+	+	?		
V_{26}	+	+	+	-	+	+	?		
V_{27}	+	-	+	+	+	+	+		
V_{28}	-	+	+	+	+	-	+		
V_{29}	+	+	+	-	-	-	+		
V_{30}	-	+	+	+	+	-	?		
V_{31}	+	-	+	+	+	?	?		
V_{32}	+	+	-	+	?	+	+		

The selection chart shows that there are only 3 different design alternatives among 32 to fulfil demands parameters which are shown in Table 4.4.

Table 4.4. The candidates for best mechanical fruit press design

Alternatives / Function	**1**	**3**	**4**
Body	Free standing monoblock	Free standing pronged	Free standing monoblock
Pressing	Side & Horizontal Handle	Side & Vertical Handle	Side & Vertical Handle
Support	Handle	Handle	Handle
Sieving	Sieve	Sieve	Sieve
Carafe	Carafe with sieve	Carafe with sieve	Carafe without sieve

The evaluation chart for wishes parameters was applied to these 3 design alternatives. The rest which is found to be not suitable are provided in appendix in in Table A-6.

There are two steps to evaluate the wishes parameters as discussed in Chapter 3. The first step is weighted objective tree (WOT) as shown in Figure 4.1 (see Figure 3.7 in Chapter 3) which was generated from the data in the requirement list, and the second one is evaluation chart (see Table 3.5 in Chapter 3) as shown in Table 4.5 which is generated from the data in the selection chart and from the WOT.

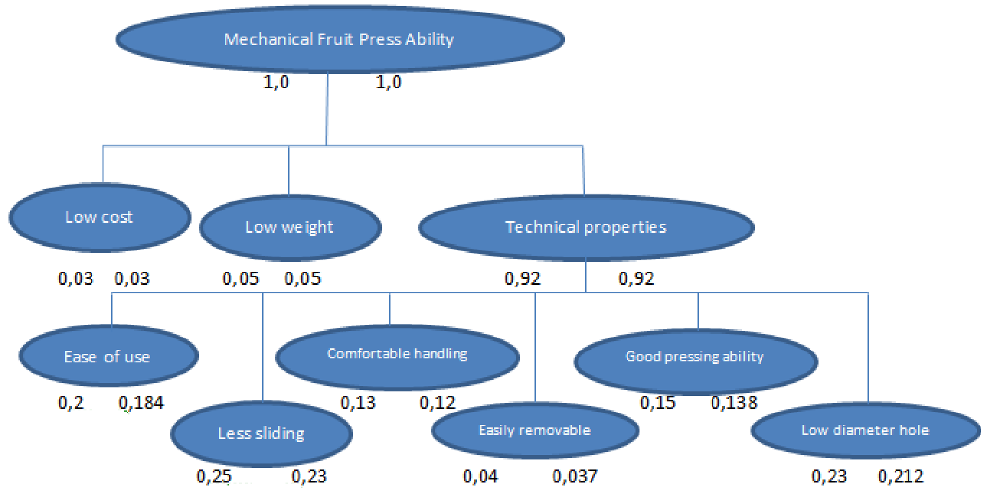
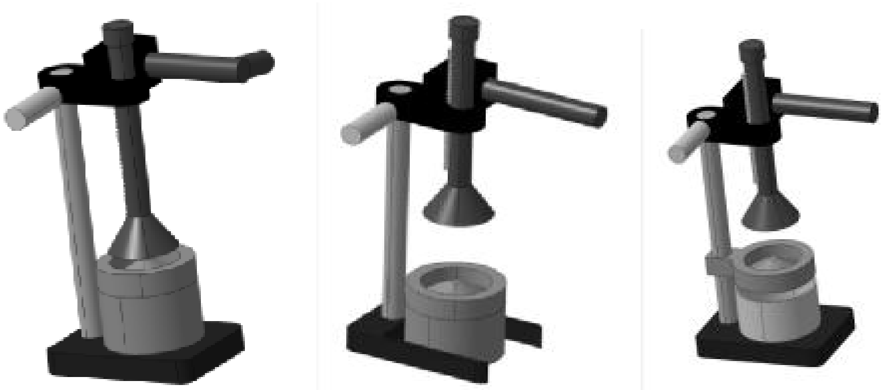


Figure 4.1. Application of WOT analyses technique for the mechanical fruit press

Table 4.5. Application of evaluation chart for mechanical fruit press design alternatives

			V_1		V_3		V_4	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.03	3	0.09	2	0.06	2	0.06
2	Low weight	0.05	3	0.15	3	0.15	3	0.15
3	Ease of use	0,184	4	0.736	3	0.552	2	0.368
4	Less sliding	0.23	4	0.92	2	0.46	2	0.46
5	Comfortable handling	0.12	3	0.36	2	0.24	2	0.24
6	Easily removable	0.037	2	0.074	2	0.074	2	0.074
7	Good press ability	0.138	4	0.552	3	0.414	3	0.414
8	Low diameter hole	0.212	3	0.636	3	0.636	3	0.636
		∑Wt.=1		**∑OWV$_1$= 3.518**		∑OWV$_3$= 2.586		∑OWV$_4$= 2.402

As it is mentioned in the previous chapter, next phase is about evaluation of these design alternatives. At this point, we have chosen VDI guideline as evaluation technique to determine the best design alternatives according to customers' requirements which enlarged upon in 3.3.4. At the final stage, the highest scoring design alternative was selected as best "design product", which is found to be V1 in Table 4.5, and the second (V3) and third best (V4) design alternatives of evaluation chart are shown in Figure 4.2. In terms of VDI guideline technique, side and horizontal handle has got higher mark than side and vertical handle because of ease of use as shown in Table 4.5.



(a) (b) (c)

Figure 4.2. (a) The best mechanical fruit press design alternative (b) The second choice (number 3 design alternative) (c) The third choice (number 4 design alternative).

Assembly parts of mechanical fruit press are shown in Figure 4.3 and large appearance of the parts in Figure A-1.

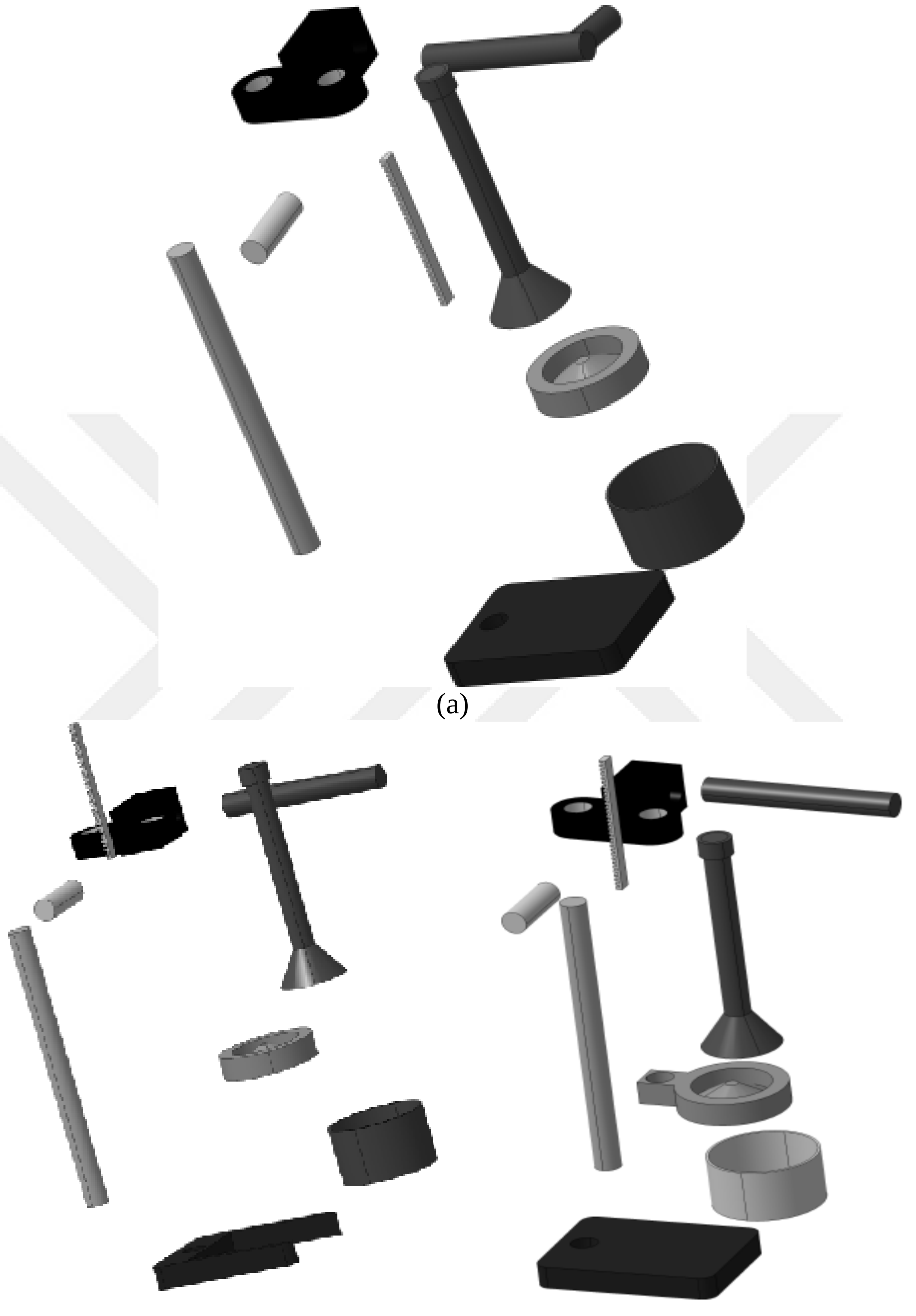


Figure 4.3. Assembly parts of (a) the best mechanical fruit press design alternative (b) The second best (number 3 design alternative) (c) The third best (number 4 design alternative).

4.1.2. Application of Morphological Design to Mechanical Pencil

Based on customers' requirement, there are eight expectations for mechanical pencil product such as low cost, less lead fracture, non-rolling body, steady lead, clean-living eraser, anti-skid grip, non-destructive grip, and easily portable as shown in Table 4.6. These requirements obtained by simple market research by interviewing with mechanical pencil users, and searching mechanical pencil user's opinion on internet Four operational necessities have been determined to fulfil customers' requirements. These necessities are body, grip type, con cap, and eraser.

Table 4.6. Customer requirements list for the mechanical pencil

	The requirements list for mechanical pencil		
	D: Demand W: Wish	Requirements	
	D (100%)	Cost of product < 10€	
	W (10%)	Low cost	
	W (90%)	**<u>Technical Properties:</u>**	
		Body	
	W (40%)	Non-rolling	
	D (100%)	Easily portable	
		Grip Type	
	W (5%)	Anti-skid	
	W (10%)	Non-destructive	
		Con Cap	
	W (15%)	Prevent lead fracture	
	W (10%)	Steady lead	
		Eraser	
	W (20%)	Clean-living	

In the light of these function parameters; some solution alternatives have been described to fulfil eight customer requirements. Next step to create morphological matrix is the description of solution alternatives. After finding of the solutions, the morphological matrix table is created as shown in Table 4.7.

Table 4.7. Morphological matrix table for the mechanical pencil

Alternatives / **Function**	**1**	**2**	**3**
Body	Hexagonal body with clips	Circular body with clips	Triangle body with clips
Grip Type	Rubber	Groove	Rubber & Groove
Cone Cap	Penetration & Lead Holder	Constant & Lead Holder	
Eraser	Rotational	Covered	

The main disadvantage of conventional morphological matrix shows up in this step. 36 (3x3x2x2) different design alternatives have been taken place as shown in appendix in Table A-12, and 5 different design alternatives have been chosen among 36 different design solutions according to demands parameters by using of the selection chart as shown in Table 4.8, where selected alternatives are shown as bold. The 5 alternatives which are more practical and adequate than the others, and they were determined as the candidates for best mechanical pencil design.

Table 4.8. Selection chart for evaluation of demands parameters of mechanical pencil

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	DECISION
V_1	+	+	+	-	-	+	?		
V_2	-	+	+	+	?	-	+		
V_3	+	+	+	+	+	+	?		
V_4	+	+	-	+	-	?	+		
V_5	-	+	+	+	-	-	?		
V_6	+	+	+	+	+	-	?		
V_7	-	+	+	+	-	-	?		
V_8	+	+	+	-	+	+	?		
V_9	+	-	+	+	-	+	?		
V_{10}	+	+	+	-	?	-	+		
V_{11}	-	+	-	+	-	+	?		
V_{12}	+	+	+	-	+	-	+		
V_{13}	+	+	+	+	-	-	?		
V_{14}	+	-	+	+	+	-	+		
V_{15}	+	+	-	-	-	?	?		
V_{16}	+	-	+	+	+	-	+		
V_{17}	+	+	-	+	-	-	?		
V_{18}	+	+	+	+	-	+	?		
V_{19}	-	+	+	+	-	-	+		
V_{20}	+	+	-	+	+	-	?		
V_{21}	+	-	+	+	-	+	?		
V_{22}	+	-	+	+	+	-	+		
V_{23}	-	+	+	+	-	-	?		
V_{24}	+	+	+	+	+	+	+		
V_{25}	+	+	-	+	+	+	?		
V_{26}	+	+	+	-	+	-	?		
V_{27}	+	-	+	+	+	?	+		
V_{28}	-	+	+	+	+	-	?		
V_{29}	+	+	+	-	+	-	+		
V_{30}	-	+	+	+	-	-	?		
V_{31}	+	-	+	+	+	-	?		
V_{32}	+	+	-	+	-	+	+		
V_{33}	+	+	-	+	-	+	?		
V_{34}	+	+	-	+	+	-	?		
V_{35}	+	+	-	+	-	-	?		
V_{36}	+	-	+	-	+	-	?		

These 5 different alternatives which were selected after selection chart evaluation are shown in Table 4.9.

Table 4.9. The candidates for best mechanical pencil design

Alternatives / Function	3	6	13	18	24
Body	Hexagonal body with clips	Hexagonal body with clips	Circular body with clips	Circular body with clips	Circular body with clips
Grip Type	Rubber	Groove	Rubber	Groove	Rubber & Groove
Cone Cap	Penetration & Lead Holder	Constant & Lead Holder	Penetration & Lead Holder	Constant & Lead Holder	Constant & Lead Holder
Eraser	Rotational	Rotational	Rotational	Rotational	Covered

In the next step, which is evaluation of wishes parameters phase, WOT analyse technique were created according to the data in the requirement list as shown in Figure 4.4, and the evaluation chart which was created according to the data in the selection chart and in WOT as shown in Table 4.10 will be applied respectively for the 5 design alternatives. In the evaluation chart stage, we benefit from VDI guidelines technique to determine the best design alternative.

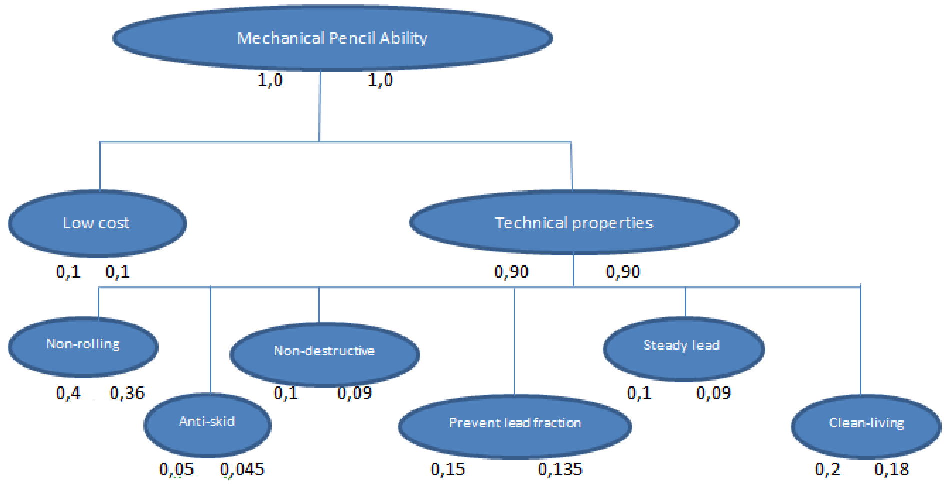


Figure 4.4. Application of WOT analyse technique for the mechanical pencil

Table 4.10. Application of evaluation chart for mechanical pencil design alternatives

			V_3		V_6		V_{13}		V_{18}		V_{24}	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.1	3	0.3	3	0.3	2	0.2	2	0.2	2	0.2
2	Non-rolling	0.36	4	1.44	4	1.44	2	0.72	2	0.72	2	0.72
3	Anti-skid	0.045	4	0.18	4	0.18	4	0.18	2	0.09	3	0.135
4	Non-destructive	0.09	4	0.36	3	0.27	4	0.36	3	0.27	4	0.36
5	Prevent lead fraction	0.135	4	0.54	3	0.405	4	0.54	3	0.405	3	0.405
6	Steady lead	0.09	4	0.36	4	0.36	4	0.36	4	0.36	4	0.36
7	Clean-living	0.18	3	0.54	3	0.54	3	0.54	3	0.54	4	0.72
		$\sum$Wt. =1		**$\sum OWV_3$= 3.72**		$\sum OWV_6$= 3.495		$\sum OWV_{13}$ = 2.9		$\sum OWV_{18}$ = 2.585		$\sum OWV_{24}$ = 2.9

After the determination of best product design solution, high scoring design alternative was selected as the best "design product" and the other design alternatives of evaluation chart are shown in Figure 4.5. In terms of VDI guideline, hexagon body has got higher mark than circular body because of stability specific to parameter of non-rolling.

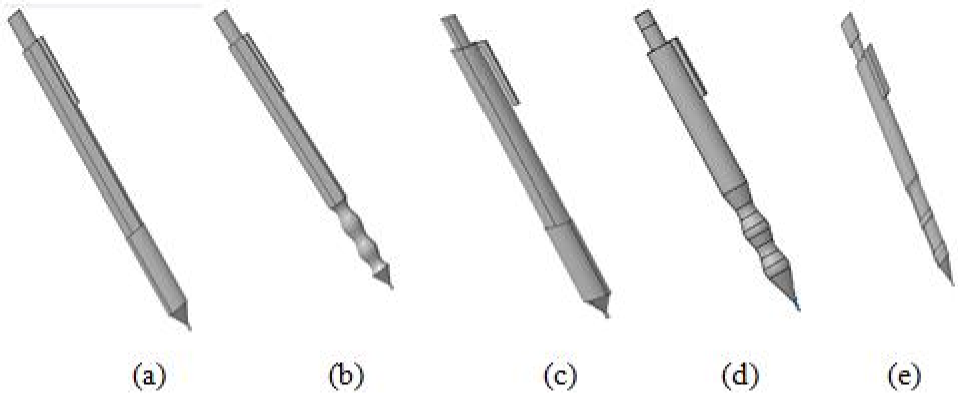


Figure 4.5. (a) The best mechanical pencil design alternative (b) The second best (number 6 design alternative) (c) The third best (number 13 design alternative) (d) The fourth best (number 18 design alternative) (e) The fifth best (number 24 design alternative) design alternatives.

Assembly parts of these mechanical pencil designs are shown in Figure 4.6 and large appearance of the parts in Figure A-2.

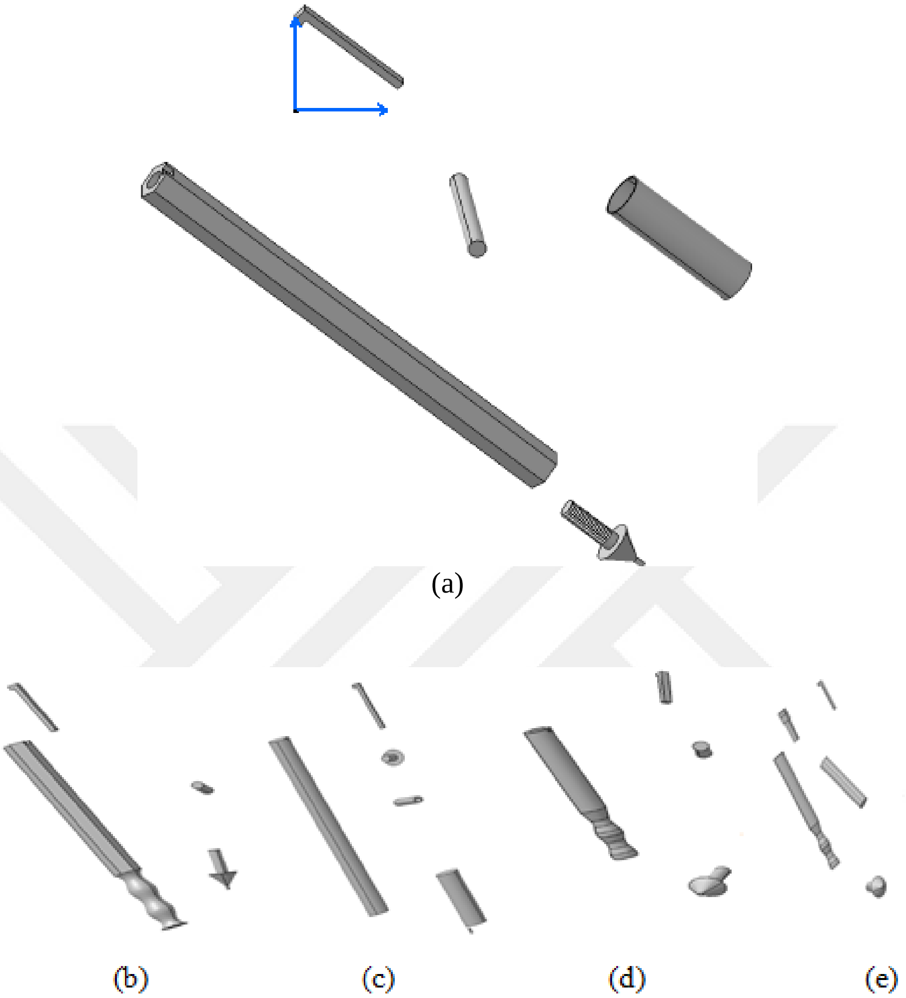


Figure 4.6. Assembly parts of (a) best mechanical pencil design alternative The second best (number 6 design alternative) (c) The third best (number 13 design alternative) (d) The fourth best (number 18 design alternative) (e) The fifth best (number 24 design alternative) design alternatives.

4.1.3. Application of Morphological Design to Manipulator Frame

In this example, we have based the practice which is given in chapter 2.4.2 that has been carried out by Oskar Ostertaga, Eva Ostertagová and Róbert Hunady (2012).

The customers expect according to market research by interviewing and internet search, nine features for manipulator frame such as ease of assemblability, manufacturability, cost, durability, corrosion resistance, ease of use, balanced, strengthen, perpetuity connection which is shown in Table 4.11. Six operational functions have been found to satisfy the customers' requests. These operational functions may array as beam cross-section type, beam fabrication, body cross-section type, body fabrication, beam and body, and conveyance mode.

Table 4.11. Customer requirements list for the manipulator frame

	The requirements list for manipulator frame		
	D: Demand W: Wish	Requirements	
	D (100%)	Cost of product < 50€	
	D (100%)	Corrosion resistance	
	W (15%)	Low cost	
	W (85%)	**Technical Properties:**	
		Beam Cross-section Type	
	W (20%)	Durability	
	D (100%)	Ease of assemblability	
		Beam Fabrication Technology	
	W (15%)	High strength	
		Body Cross-section Type	
	W (20%)	Balanced	
	D (100%)	Ease of assemblability	
		Body Fabrication Technology	
	W (15%)	Manufacturability	
		Beam & Body Connection	
	W (20%)	Perpetuity connection	
		Conveyance Mode	
	W (10%)	Ease of use	

To realize these functions, some design solutions have been obtained which are shown in Table 4.12.

Table 4.12. Morphological matrix table for the manipulator frame

Alternatives / Function	1	2	3
Beam Cross-section Shape	Open 2xL	Closed 2xU	Open H
Beam Fabrication Technology	Cast	Drawn	
Body Cross-section Shape	Rectangular	Round	
Body Fabrication Technology	Cast	Drawn	
Beam and Body Connection	Weld		
Conveyance Mode	Basket	Hook	

Functions in Table 4.12 provided 48 (3xx2x2x1x2) different design alternatives as all the design alternatives are shown in appendix in Table A-18.

These design alternatives were determined as the candidates for best manipulator frame design. This is made using the selection chart and by considering demands parameters as shown in Table 4.13.

Table 4.13. Selection chart for the evaluation of demands parameters of manipulator frame

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	Decision
V_{1}	+	+	-	+	-	+	?		
V_{2}	+	-	+	+	?	-	+		
V_{3}	+	-	+	+	+	?	+		
V_{4}	+	+	+	+	-	?	+		
V_{5}	-	+	+	+	-	-	?		
V_{6}	+	+	+	-	+	-	?		
V_{7}	+	+	+	-	-	-	?		
V_{8}	-	+	+	+	+	+	?		
V_{9}	-	+	+	+	-	+	?		
V_{10}	+	-	+	-	?	-	+		
V_{11}	+	+	-	+	-	+	?		
V_{12}	+	+	+	-	+	-	+		
V_{13}	-	+	+	+	-	-	?		
V_{14}	+	+	+	-	+	-	+		
V_{15}	+	+	-	+	-	?	?		
V_{16}	+	+	+	-	+	-	+		
V_{17}	-	+	+	+	-	-	?		
V_{18}	+	-	+	+	-	+	?		
V_{19}	+	+	-	+	-	-	+		
V_{20}	+	+	+	-	+	-	?		
V_{21}	-	+	+	+	-	+	?		
V_{22}	+	+	+	-	+	-	+		
V_{23}	-	+	+	+	-	-	?		
V_{24}	+	+	+	-	+	+	+		
V_{25}	-	+	+	+	+	?	+		
V_{26}	+	+	+	-	+	-	?		
V_{27}	+	+	+	+	+	?	+		
V_{28}	+	+	+	-	+	-	?		
V_{29}	+	+	+	-	+	+	+		
V_{30}	-	+	-	+	-	-	?		
V_{31}	+	-	+	+	-	-	?		
V_{32}	+	+	-	+	-	?	+		
V_{33}	+	+	+	+	-	+	?		
V_{34}	+	+	-	+	+	+	?		
V_{35}	+	+	-	-	-	-	?		
V_{36}	+	-	+	+	+	-	?		
V_{37}	+	+	+	?	-	+	?		
V_{38}	+	-	+	+	+	-	+		
V_{39}	+	+	-	+	?	+	?		
V_{40}	+	+	+	-	+	?	+		
V_{41}	+	+	+	-	-	-	?		
V_{42}	+	-	+	?	+	-	+		
V_{43}	+	+	-	+	-	?	+		
V_{44}	+	+	+	-	+	-	?		
V_{45}	-	+	+	+	-	?	?		
V_{46}	+	+	+	-	-	+	?		
V_{47}	+	+	?	+	-	-	+		
V_{48}	+	+	-	-	+	-	?		

Four different design alternatives which operate easier and more practical have been selected investigating 48 different design solutions which are shown in Table 4.14.

Table 4.14. The candidates for best manipulator frame design

Alternatives / Function	4	25	27	33
Beam C- S. S.	Open 2xL	Closed 2xU	Closed 2xU	Open H
Beam F.T.	Cast	Drawn	Drawn	Cast
Body C –S. S.	Rectangular	Rectangular	Rectangular	Rectangular
Body F. T.	Drawn	Cast	Drawn	Cast
Beam and Body C.	Weld	Weld	Weld	Weld
C. M.	Perforated Basket	Closed Basket	Closed Basket	Closed Basket

After determining the suitable design alternatives for demands parameters, WOT analyse technique, which generated according to the data in the requirement list as shown in Figure 4.7. And then the evaluation chart, which was generated according to the data in the selection chart and in WOT as shown in Table 4.15, have been applied respectively to designate the optimum design alternatives. In this stage, VDI guideline technique was implemented to determine the best design alternative.

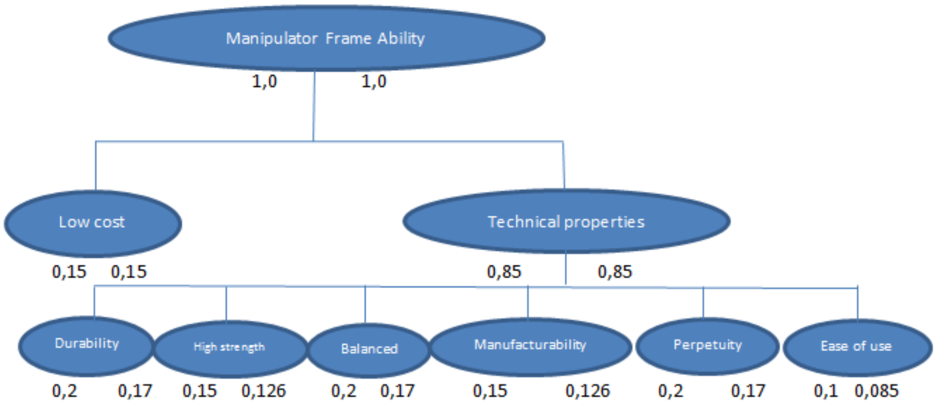


Figure 4.7. Application of WOT analyse technique for manipulator frame

Table 4.15. Application of evaluation chart for the manipulator frame design alternatives

			V_4		V_{25}		V_{27}		V_{33}	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.15	3	0.45	2	0.3	3	0.45	2	0.3
2	Durability	0.17	3	0.51	3	0.51	3	0.51	2	0.34
3	High strength	0.126	3	0.378	3	0.378	4	0.504	3	0.378
4	Balanced	0.17	4	0.68	4	0.68	4	0.68	4	0.68
5	Manufacturability	0.126	3	0.378	4	0.504	3	0.378	4	0.504
6	Perpetuity	0.17	4	0.68	4	0.68	4	0.68	4	0.68
7	Ease of use	0.085	3	0.255	4	0.34	4	0.34	4	0.34
		$\sum Wt. = 1$		$\sum OWV_4 = 3.331$		$\sum OWV_{25} = 3.392$		**$\sum OWV_{27} = 3.542$**		$\sum OWV_{33} = 3.222$

After the determination of best "product design" solution, high scoring design alternative was selected as the best design product. The evaluation chart given in Table 4.15 also provides the promising design alternatives. Figure 4.8 also gives design outputs for all the high scoring design alternatives.

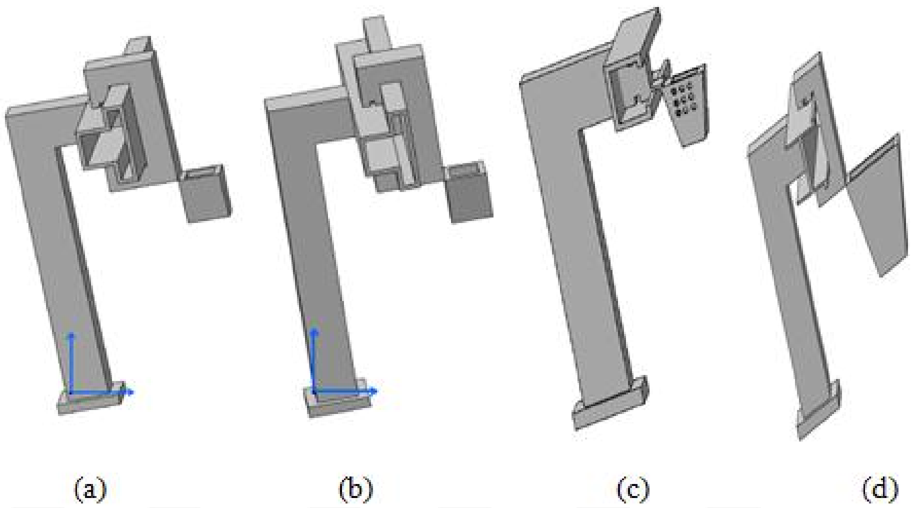
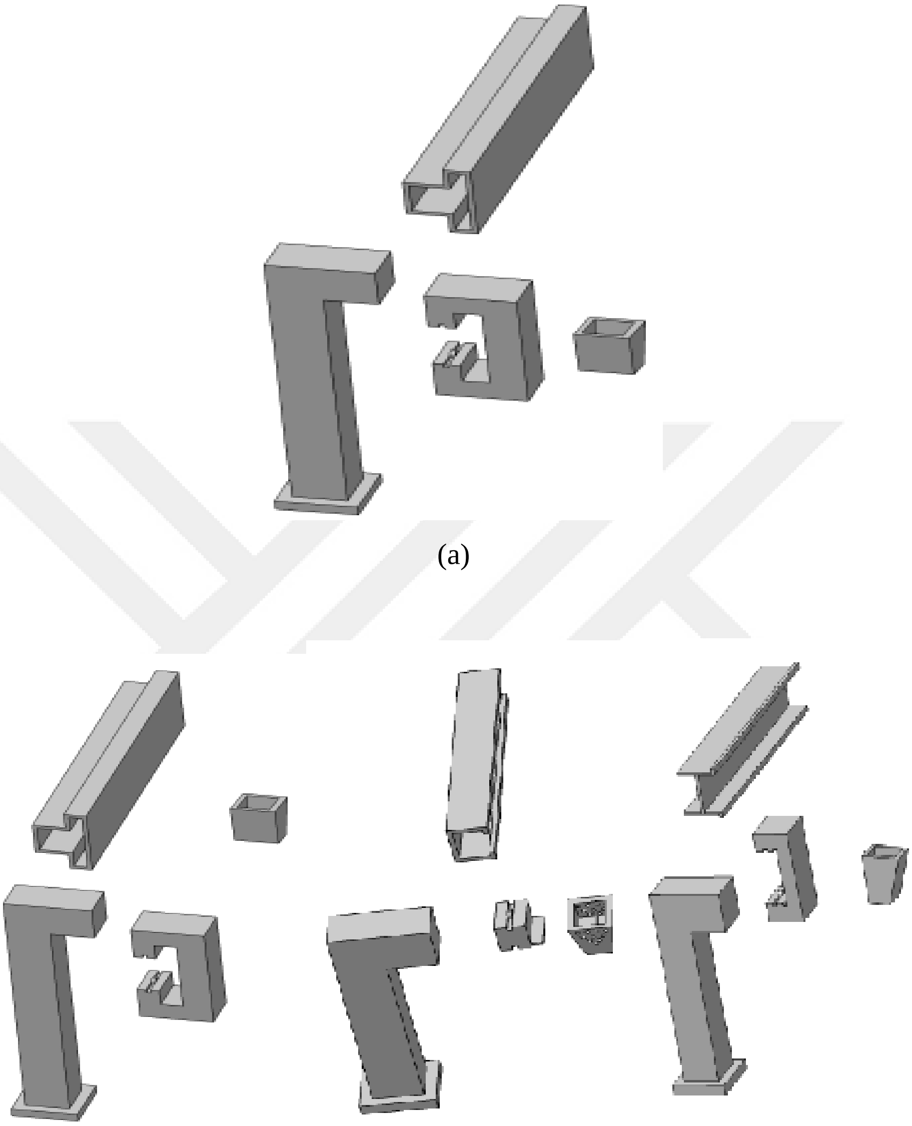


Figure 4.8. (a) The best manipulator frame design alternative (b) The second best (number 25 design alternative) (c) The third best (number 4 design alternative) (d) The fourth (number 33 design alternative) design alternatives.

Assembly parts of manipulator frame designs are given in Figure 4.9 and large appearance of the parts in Figure A-2.



(a)

(b) (c) (d)

Figure 4.9. Assembly parts of (a) The best manipulator frame design alternative (b) The second best (number 25 design alternative) (c) The third best (number 4 design alternative) (d) The third best (number 33 design alternative) design alternatives

4.2. Application of the New Approach to Systematic Product Design to Sample Products

In this phase of the study, the selected sample products were designed by using the new approach to systematic product design. The design process of new approach based on the Figure 3.3 are going to be applied and explained for the selection of the best design alternatives for the sample products. We had mention at previous chapter the original condition of requirement list, WOT schema, evaluation chart, and selection chart in Table 3.2 (b), Figure 3.8, Table 3.6, and Table 3.4 respectively for the new approach to systematic product design method.

4.2.1. Application of the New Approach to Systematic Product Design for Mechanical Fruit Press

We specified customer requirements in 4.1.1. as low cost, low weight, corrosion resistance, less study, comfortable handling, easily removable, good pressing ability, sieve, and ease of use based on the market research for mechanical fruit press, and detected parameters to fulfil the customers' requirements as body, pressing, support, sieving, and carafe at the first step of the new approach to systematic product design given in Chapter 3. Based on the new approach (see Table 3.2 (b) in Chapter 3), the designers should evaluate wishes parameters individually for technical properties of product. Requirement list table, which is shown in Table 4.16, is created in the light of customer request.

Table 4.16. Requirement list for mechanical fruit press based on customers' requirements

	The requirements list for mechanical fruit press		
	D: Demand W: Wish	Requirements	
	D (100%) D (100%) D (100%) W (30%) W (30%) W (40%) W (25%) W (30%) W (45%) W (30%) W (15%) W (25%) W (30%) W (40%) W (30%) W (30%) W (100%)	Corrosion Resistance Cost of product < 20€ Hole dimeter < 10 mm **Technical Properties:** **Body** Less sliding Low weight Low cost **Pressing** Low weight Low cost Good press ability **Support** Comfortable handling Easily removable Low weight Low cost **Sieving** Low diameter hole Low weight Low cost **Carafe** Ease of use	

As given in Figure 3.3 of chapter 3, the next stage of new approach to systematic product design is the evaluation stage. In this stage we have used the combination of VDI guideline technique and weighted objective tree (WOT) method. However, evaluation is applied separately to the technical properties of mechanical fruit press which are shown in Table 4.17 for body of mechanical fruit press. The design alternatives for required functions had been determined in Table 4.2. We benefit from requirement list to create the WOT schema as shown in Figure 4.10 (see Figure 3.8 in Chapter 3). In the case of generating evaluation chart (see Table 3.6 in Chapter 3), we benefit from WOT data. The rest of evaluation for technical properties of mechanical fruit press is shown in appendix in Table A-21, and the best alternatives were shown as bold.

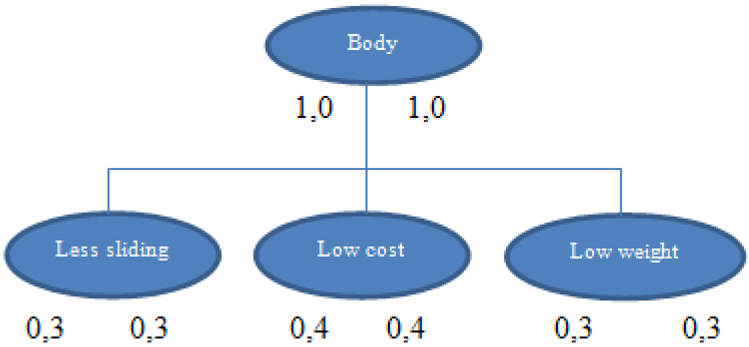


Figure 4.10. Application of WOT schema of mechanical fruit press

Table 4.17. Application of evaluation method to technical properties of mechanical fruit press

			Free standing monoblock		Free standing pronged		Lockable monoblock		Lockable pronged	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Less sliding	0.3	3	0.9	2	0.6	4	1.2	3	0.9
2	Low cost	0.4	3	1.2	2	0.8	1	0.4	0	0.0
3	Low weight	0.3	2	0.6	4	1.2	1	0.3	3	0.9
		∑Wt.=1		**$\sum OWV_1$= 2.7**		$\sum OWV_2$= 2.6		$\sum OWV_3$= 1.9		$\sum OWV_3$= 1.8

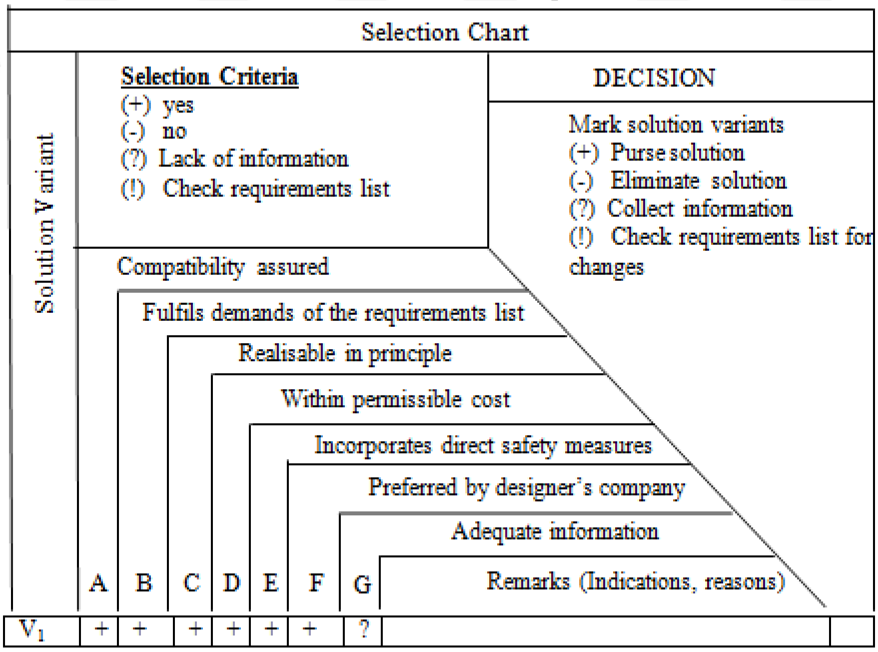
After the implementation of this combination, we have selected high scoring design alternative for all the parts of the technical properties separately. Thus, evaluation of wishes parameters is completed. After the completion of WOT analyse, we selected high scoring alternatives for each technical parts. In the light of this information, general evaluation chart was generated as shown in Table 4.18. The function of design alternatives in general evaluation chart was determined according to evaluation chart in Table 4.17. The rest of evaluation of function design alternatives are in Table A-21 for mechanical fruit press.

Table 4.18. The general evaluation chart of mechanical fruit press

		V_1
1	**Free standing monoblock**	2.7
2	**Side& Horizontal handle**	3.2
3	**Handle**	4.0
4	**Sieve**	4.0
5	**Carafe with sieve**	4.0
		$\sum V_1$= 17.9

The selection chart (see Table 3.4 in Chapter 3), which is shown in Table 4.19, is implemented to the designed product to determine whether it fulfils the demands parameter or not. If the high scoring design alternative does not fulfil first four demand parameters, the designers should try the second high scoring design alternative.

Table 4.19. The selection chart of mechanical fruit press



After the application of all phases, we reached the end of the best design alternative which is found to be the same one with morphological method that is shown in Figure 4.1.

4.2.2. Application of the New Approach to Systematic Product Design for Mechanical Pencil

Based on customers' requirement, there are eight expectations for mechanical pencil product such as low cost, less lead fracture, non-rolling body, steady lead, clean-living eraser, anti-skid grip, non-destructive grip, and easily portable. In response to these expectations, four operational necessities have been determined to fulfil customers' requirements. These necessities are body, grip type, con cap, and eraser as mentioned in 4.1.2. We have evaluated the customers' requirements as demands and wishes which are shown in Table 4.20.

Table 4.20. Requirement list for mechanical pencil based on customers' requirements

	The requirements list for mechanical pencil		
	D: Demand W: Wish	Requirements	
	D (100%)	Cost of product < 10€	
	D (100%)	Easily portable	
		Technical Properties:	
		Body	
	W (45%)	Non-rolling	
	W (55%)	Low cost	
		Grip Type	
	W (20%)	Anti-skid	
	W (45%)	Non-destructive	
	W (35%)	Low cost	
		Con Cap	
	W (40%)	Prevent lead fracture	
	W (40%)	Steady lead	
	W (20%)	Low cost	
		Eraser	
	W (60%)	Clean-living	
	W (40%)	Low cost	

Wishes parameters are evaluated individually for technical properties of product. The design alternatives for required functions had been determined in Table 4.7.

As we have discussed previously, wishes parameters were evaluated with the combination of VDI guideline and WOT evaluation techniques. WOT schema, which is shown in Figure 4.11, was generated by using the information given in the requirement list (see Table 4.20). The combination table is shown in Table 4.21 for body of mechanical pencil and the remaining evaluation for the technical properties of mechanical pencil are shown in appendix in Table A-26, and the best alternatives of mechanical pencil functions were determined as bold.

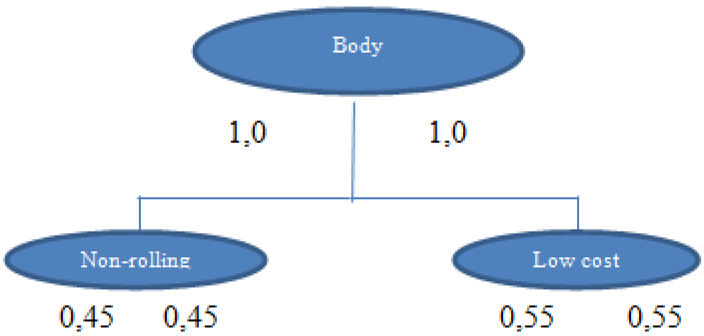


Figure 4.11. Application of WOT schema of mechanical pencil

Table 4.21. Application of evaluation method to technical properties of mechanical pencil

			Hexagonal body with clips		Circular body with clips		Triangle body with clips	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Non-rolling	0.45	3	1.35	2	0.9	4	1.8
2	Low cost	0.55	3	1.65	2	1.1	4	2.2
		∑Wt.=1		$\sum OWV_1$= 3.0		$\sum OWV_2$= 2.0		**$\sum OWV_3$= 4.0**

After completion of WOT analysis, general evaluation chart was generated from high scoring alternatives for each technical parts as shown in Table 4.22.

Table 4.22. The general evaluation chart of (a) high scoring mechanical pencil (b) second high scoring mechanical pencil

(a)

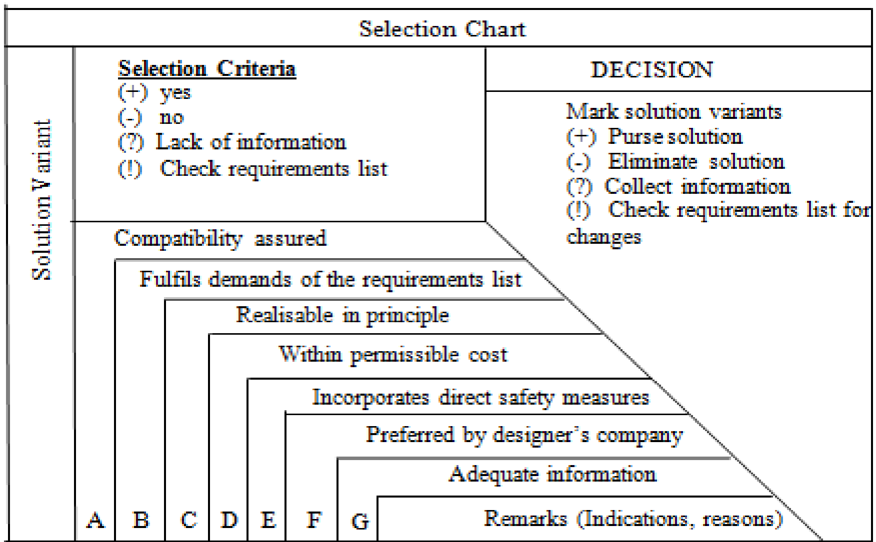
		V_1
1	**Triangle body with clips**	4.0
2	**Rubber**	3..35
3	**Penetration & Lead Holder**	3.6
4	**Rotational**	3.6
		$\sum V_1$= 14.55

(b)

		V_2
1	**Hexagonal body with clips**	3.0
2	**Rubber**	3.35
3	**Penetration & Lead Holder**	3.6
4	**Rotational**	3.6
		$\sum V_2$= 13.55

In the next phase after evaluation of wishes parameters, we have used selection chart which is shown in Table 4.23 for the final evaluation of the design alternatives. We have to select the high scoring design alternative in the evaluation of wishes parameters according to general evaluation chart.

Table 4.23. The selection chart of mechanical pencil



	A	B	C	D	E	F	G	Remarks	
V_1	+	+	-	+	+	+	?		
V_2	+	+	+	+	+	+	?		

The results of selection chart evaluation shows that the first design alternatives did not fulfil the indispensable parameters. Hence, we replaced body alternative with second high scoring one as shown in Table 4.22 (b) because of "- "sign. The mean of "-" sign is related the manageable of product. For this reason, we changed the body of pencil because triangle body is not suitable to mount a grip. Thus, we obtained second design product. Second design alternative fulfilled the notification, and this is the same product with morphological method which shown in Figure 4.5 (a).

4.2.3. Application of the New Approach to Systematic Product Design for Manipulator Frame

Based on market research, there are nine features required by customers for manipulator frame such as ease of assemblability, manufacturability, cost, durability, corrosion resistance, ease of use, balanced, strengthen, perpetuity connection. In return for these expectations, six operational functions have been found to meet the customers' requests such as beam cross-section type, beam fabrication, body cross-section type, body fabrication, beam and body, and conveyance mode as mentioned 4.1.3. The customers' requirement has been separated as demands and wishes same as before. The separation of requirements is shown in Table 4.24. The design alternatives for required functions of manipulator frame had been determined in Table 4.12.

Table 4.24. Requirement list for manipulator frame based on customers' requirements

	The requirements list for manipulator frame design		
	D: Demand W: Wish	Requirements	
	D (100%)	Cost of product < 50€	
	D (100%)	Corrosion resistance	
	D (100%)	Ease of assemblability	
		Technical Properties:	
		Beam Cross-section Type	
	W (55%)	Durability	
	W (45%)	Low cost	
		Beam Fabrication	
	W (65%)	High strength	
	W (35%)	Low cost	
		Body Cross-section Type	
	W (60%)	Balanced	
	W (40%)	Low cost	
		Body Fabrication	
	W (65%)	Manufacturability	
	W (35%)	Low cost	
		Beam & Body Connection	
	W (70%)	Perpetuity connection	
	W (30%)	Low cost	
		Conveyance Mode	
	W (55%)	Ease of use	
	W (45%)	Low cost	

In the next phase of new approach to systematic design method, the evaluation of wishes parameters with the combination of VDI guideline and WOT evaluation techniques have been used based on given in chapter 3. As stated previously, we benefit from requirement list to create the WOT schema as shown in Figure 4.12. In the case of generating the evaluation chart, we benefit from WOT data.

We applied WOT analyse technique to all parts of technical properties one by one. The combination of wishes evaluation table is shown in Table 4.25 for beam cross-section type of manipulator frame. The rest of evaluation for technical properties of manipulator frame is shown in appendix in Table A-31, and the best alternatives of mechanical pencil functions were determined as bold.

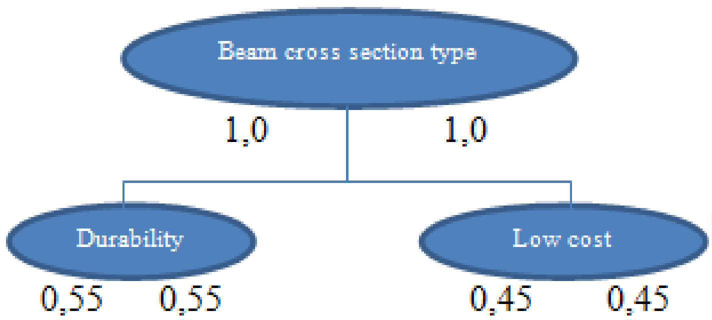


Figure 4.12. Application of WOT schema of manipulator frame

Table 4.25. Application of evaluation method for technical properties of manipulator frame

			Open 2xL		Closed 2xU		Open H	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Durability	0.55	3	1.65	4	2.2	2	1.1
2	Low cost	0.45	2	0.9	3	1.35	2	0.9
		$\sum$Wt.=1		$\sum OWV_1$= 2.55		**$\sum OWV_2$= 3.55**		$\sum OWV_3$= 2.0

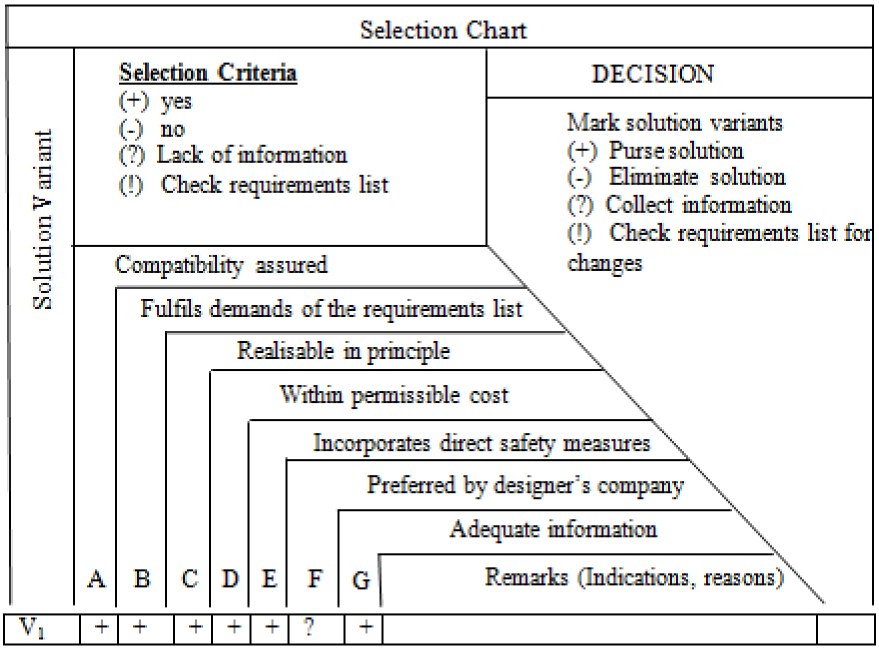
After completion of the WOT analyse, we select high scoring alternatives for each technical parts separately. Hereunder, general evaluation chart was generated as shown in Table 4.26, and this chart will be used for selection chart.

Table 4.26. The general evaluation chart of manipulator frame

		V_1
1	Closed 2xU	3.55
2	Drawn	3.3
3	Rectangular	3.0
4	Cast	2.65
5	Weld	4.0
6	Closed basket	2.55
		$\sum V_1$= 19.05

In final decision stage of new approach to systematic product design method, the selection chart evaluation technique has to be applied for demands parameters depends on high scoring design alternative for wishes parameters. The selection chart for manipulator frame is shown in Table 4.27.

Table 4.27. The selection chart of manipulator frame



Following the implementation of all design stages, we concluded that the best design alternative is not the same as the one obtained using the morphological method which is given in Figure 4.5 (a). There is one difference between two results. This difference is about body fabrication. The new systematic product design method suggests casting for body fabrication according to WOT analyse as shown in appendix in Table A-31, but morphological design method suggests drawing for body fabrication as shown in Figure 4.5 (b). The reason of this difference is in design process. In morphological design, functions of design alternative are determined together while new approach to systematic product design determines separately.

4.3. Comparison of Morphological Design and the New Approach to Systematic Product Design Methods

There are some similarities and discrepancies between these two methods. In the following sections, these similarities and discrepancies are explained.

4.3.1. Overall

There are several similar stages of the two systematic design methodologies studied in this thesis, as can be seen in the design processes given in Table 3.2. Some of these similarities are to gather customers' requirements, find solutions for customer' request and implementation of evaluation techniques like the combination of WOT analyse and VDI guidelines.

Opposite to these similarities, there are several differences between morphological design and the new approach to systematic product design methodologies which are given in Figure 3.5. The following sections analyse these differences.

4.3.2. Based on Tools

Besides the similarities between these methodologies, there are many important discrepancies which are shown in Figure 3.5. This essential difference brings in practicability and convenience to morphological methodology. Due to this difference, the designers can reduce the vast numbers of design alternatives significantly which are obtained by morphological design matrix, thus duration of design reduces because of less design alternatives which must be evaluated. First discrepancy is in the creation of requirement list. In the creation stage of requirement list of morphological design methodology, common demand and wish parameters are indicated at the top of the table by the designers. In addition, total wish ratio of part of technical properties is specified as the rest of total ratio of common wish parameters as well. In the new approach to systematic product design, all demands parameters are indicated at the top of the table, and total wish ratio of each functions have to be 100%.

The number of design alternatives to be evaluated for morphological design was shown in Table 4.3, Table 4.8, and Table 4.13 respectively. On the other hand, the number of design alternatives to be evaluated for the new approach to systematic product design was shown in Table 4.19, Table 4.23, and Table 4.27 respectively. The comparison of selection charts is shown in Table.28 (a) for morphological design of mechanical pencil and Table.28 (b) for the new approach to systematic product design of mechanical pencil, respectively.

Table 4.28. The selection chart of (a) morphological design of mechanical pencil (b) the new approach to systematic product design of mechanical pencil

(a)

Selection Chart

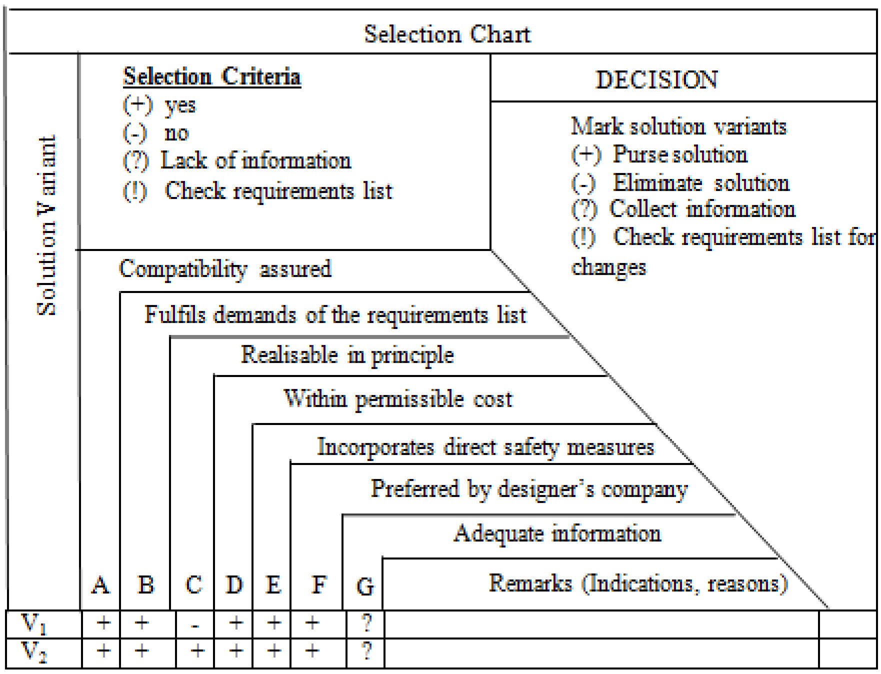
Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	Decision
V_1	+	+	+	-	-	+	?		
V_2	-	+	+	+	?	-	+		
V_3	+	+	+	+	+	+	?		
V_4	+	+	-	+	-	?	+		
V_5	-	+	+	+	-	-	?		
V_6	+	+	+	+	+	-	?		
V_7	-	+	+	+	-	-	?		
V_8	+	+	+	-	+	+	?		
V_9	+	-	+	+	-	+	?		
V_{10}	+	+	+	-	?	-	+		
V_{11}	-	+	-	+	-	+	?		
V_{12}	+	+	+	-	+	-	+		
V_{13}	+	+	+	+	-	-	?		
V_{14}	+	-	+	+	+	-	+		
V_{15}	+	+	-	-	-	?	?		
V_{16}	+	-	+	+	+	-	+		
V_{17}	+	+	-	+	-	-	?		
V_{18}	+	+	+	+	-	+	?		
V_{19}	-	+	+	+	-	-	+		
V_{20}	+	+	-	+	+	-	?		
V_{21}	+	-	+	+	-	+	?		
V_{22}	+	-	+	+	+	-	+		
V_{23}	-	+	+	+	-	-	?		
V_{24}	+	+	+	+	+	+	+		
V_{25}	+	+	-	+	+	+	?		
V_{26}	+	+	+	-	+	-	?		
V_{27}	+	-	+	+	+	?	+		
V_{28}	-	+	+	+	+	-	?		
V_{29}	+	+	+	-	+	-	+		
V_{30}	-	+	+	+	-	-	?		
V_{31}	+	-	+	+	+	-	?		
V_{32}	+	+	-	+	-	+	+		
V_{33}	+	+	-	+	-	+	?		
V_{34}	+	+	-	+	+	-	?		
V_{35}	+	+	-	+	-	-	?		
V_{36}	+	-	+	-	+	-	?		

(b)



Other contrasts between morphological and new approach to systematic product design methods is in the final evaluation phase. For morphological design, exact decision is made by implementation of the combination of VDI guideline technique and WOT analysis to all design alternatives after selection chart evaluation. After this implementation, high scoring design alternatives is accepted as the optimum solution to design the product. In the new approach to systematic product design method, for wishes requirement of customers, all function alternatives are evaluated individually by using the combination of VDI guideline technique and WOT analysis. This evaluation stage is applied for wishes parameters and not determines the exact decision. Second phase of evaluation stage is also exact decision stage.

The combination of high scoring wishes parameters creates a new product. This product is evaluated by the selection chart to determine whether it fulfils the demands parameter or not. There is a crucial point in this step. This is the fulfilment of the first four notifications in the selection chart because these are the most important parameters for exact decision. If the new product fulfils the demand parameters, the designers make exact decision for optimum product. In case of unfulfilled ones, this process is applied for the second high scoring product according to wishes parameters as given in Figure 3.4. The differences and similarities of both design methods are shown step by step in Table 4.29.

Table 4.29. The design process of morphological design and the new approach to systematic product design

Steps of Design Methodologies	Morphological Design Methodology	The New Approach to Systematic Product Design
Requirement List	• First step of morphological design methodology • Implement to obtain the customers' requirement • Common demand and wish parameters are indicated at the top of the table • Total wish ratio of part of technical properties is specified as the rest of total ratio of common wish parameters	• First step of the new approach to systematic product design methodology • Implement to obtain the customers' requirement • All demands parameters are indicated at the top of the table • Total wish ratio of each functions have to be 100%
Determination of Alternative Solutions for Functions	• Second step of morphological design methodology • Alternative solutions are determined for each functions • Total number of design solutions is calculated by the multiplying of solution number of each function with solution numbers of all functions.	• Second step of the new approach to systematic product design methodology • Alternative solutions are determined for each functions • Total number of design solutions is calculated by the multiplying of solution number of each function with solution numbers of all functions.

Table 4.29. (Continue)

Selection Chart	• Third step of morphological design • All design alternatives are evaluated in this step	• Fifth and last step of the new approach to systematic product design • Only high scoring design alternatives are evaluated in this step which is obtained at evaluation chart
Wot Analysis	• Forth step of morphological design • Wish parameters are evaluated together	• Third step of the new approach to systematic product design • Wish parameters are evaluated separately for each functions
Evaluation Chart	• Fifth and last step of morphological design • High scoring design alternatives is accepted as the best design	• Forth step of the new approach to systematic product design • High scoring design alternatives for each functions are determined and gathered

The results obtained do not vary from person to person. This is because the designers apply design process of the new approach to systematic product design and morphological design according to customer requirement.

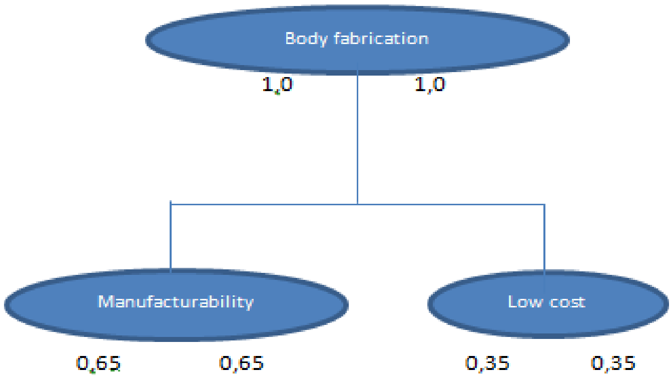
The morphological method and the new approach to systematic design product method were implied to three sample products. According to these implementations, mechanical fruit press and mechanical pencil have given same products while manipulator frame design has given different product. The reason of difference is related to fabrication method of body. Morphological method has suggested drawing process for body fabrication while the new approach to systematic design product has suggested casting. Actually, both of these methods have showed us that casting is the better way for body fabrication instead of drawing. In morphological method, all of wish parameters of function design alternatives evaluated together. Therefore, high scoring design alternatives is selected as the best one in spite of some of low point function design alternatives. In comparison with morphological method each wishes parameters evaluated separately in the new approach to systematic product design. Hence, the designers consider only highest scoring function design alternatives to evaluate in selection chart. The comparison of body fabrication method between morphological method and the new approach to systematic design product method is shown in Table 4.30 (a), and Table 4.30 (b) respectively. These four different design alternatives in Table 4.30 (a) had been clarified in Table 4.13.

Table 4.30. The comparison of body fabrication method between (a) morphological method and (b) the new approach to systematic design product method

(a)

			V_4		V_{25}		V_{27}		V_{33}	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.15	3	0.45	2	0.3	3	0.45	2	0.3
2	Durability	0.17	3	0.51	3	0.51	3	0.51	2	0.34
3	High strength	0.126	3	0.378	3	0.378	4	0.504	3	0.378
4	Balanced	0.17	4	0.68	4	0.68	4	0.68	4	0.68
5	**Manufacturability**	**0.126**	**3**	**0.378**	**4**	**0.504**	**3**	**0.378**	**4**	**0.504**
6	Perpetuity	0.17	4	0.68	4	0.68	4	0.68	4	0.68
7	Ease of use	0.085	3	0.255	4	0.34	4	0.34	4	0.34
		$\sum$Wt. =1		$\sum OWV_4$= 3.331		$\sum OWV_{25}$ = 3.392		**$\sum OWV_{27}$ = 3.542**		$\sum OWV_{33}$ = 3.222

(b)



			Cast		Drawn	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Manufacturability	0.65	3	1.95	2	1.3
2	Low cost	0.35	2	0.7	3	1.05
		∑Wt=1		$\sum OWV_1$= **2.65**		$\sum OWV_2$= 2.35

The rest of technical properties for the evaluation of manipulator frame functions are given in Table A-31 for new approach to systematic product design.

As we said before, the reason of this difference is in design process. In morphological design, functions of design alternative are determined together while new approach to systematic product design determines the functions separately in WOT analysis stage.

In generally, morphological method and the new approach to systematic design product have given us the same function alternatives for products. In spite of these similarities, some function alternatives of final products may be different because of the differences of design process. In my opinion, the new approach to systematic product design is much shorter and also it provides better product design than morphological design because of separately evaluation of wishes parameters. In addition to that, the designers should implement the new approach to systematic product design methodology for various mechanical products for conclusive research.

5. CONCLUSION AND FUTURE WORK

Systematic product design methodologies contain many sub stages. Specific to morphological design, these sub stages cause to some drawbacks in terms of designers. The most important disadvantage is about the number of solution. The morphological design methodology generates too many solutions in selection chart stage which is the evaluation stage of customer demands, and some of which may not even be logical. Because of that reason, the designers consumes a lot of time to determine the best design.

The main aim of this research is to remove this disadvantage. We have proposed a new systematic product design approach for this purpose which is shown in Figure 3.3. To achieve this goal, we have reduced the number of design alternatives. We began with some changes in design stage of morphological design which is shown in Figure 3.1. Firstly, WOT analyse technique was implemented before the selection chart in new approach. Besides, there is a difference in WOT analyse technique. In morphological design methodology, WOT analyse was applied to whole of product according to wishes parameters. In contrast to morphological one, WOT analyse was applied for each assembly parts separately in new systematic product design approach. The results obtained were determined in evaluation chart, and the high scoring design alternative selected as the best design according to customer wishes.

Thus, there was only one design alternative in selection chart stage. If high scoring design alternative fulfils the demands parameter in selection chart, the designers can make exact decision. If it does not fulfil the demands parameter in selection chart, the designers have to select second high scoring design alternative to evaluate in selection chart.

At the end of these processes, there is a comparison stage between both of the design methods. This comparison may cause to two different results. First one is, if the best design alternatives of these design methodologies are the same, the new approach gains advantage of time. Second one is, if there is different result between the design alternatives. This means that the new approach does not only gain advantage of time but also provide better design alternative. This is because the highest scoring function design alternatives consider in the new approach while making an overall rating in morphological design according to wishes parameters.

In this study, we have implemented these design processes to 3 different products which are mechanical fruit press, mechanical pencil, and manipulator frame. At the result of the comparison stage, we obtained same product in mechanical fruit press. Contrary to this, the best mechanical pencil in morphological design is found to be the same with second high scoring product design in the new approach.

Contrary to these results, there was a difference for manipulator frame design between two design methodologies. This was due to the selected fabrication method. In morphological design, body of manipulator frame was fabricated by casting while it was fabricated by drawing in the new approach. As we explained in Chapter 4.3.2., both of these methods have showed us that casting is the better way for body fabrication instead of drawing. The reason of this difference is the determination method of wishes parameters in WOT analysis. In the new approach, each wishes parameters evaluated separately while all of wish parameters of function design alternatives evaluated together in morphological design. Thus, we may coclude that morphological design method may misguide the designers.

As a summary, the results of these two design methodologies are the same for two sample products. This means that, the new approach has provided a better product for one sample. In the light of these studies, we know for sure that the new approach to systematic product design is not only much shorter than morphological method but also it reveals a better design. The reason is that, the designers can select the best function design alternatives in the new approach because of separate evaluation of wishes parameters. However, implementations of the new approach to systematic product design to various mechanical products are vital importance to achieve exact decision.

REFERENCES

Avdiu, S., Morina, R., and Ramadani, R., 2012. Design of Machine Vice Based on Morphological Matrix Method. 16th International Research/Expert Conference. Dubai, UAE.

Bessant, J., and Francis, D., 1997. Implementing the New Product Development Process. Centre for Research in Innovation Management, University of Brighton, Falmer, Brighton, UK.

Borılle, A. V., and Gomes, J. D. O., 2011. Selection of Additive Manufacturing Technologies Using Decision Methods. P: 37-41.

Brooks, F., 2003. Is There a Design of Design? NSF Workshop on Science of Design: Software-Intensive Systems.

Brooks, F., 2007. The Design of Design. Keynote Presentation at The Design Requirements Workshop, Cleveland.

Brooks, F., 2010. The Design of Design: Essays From a Computer Scientist. Addison-Wesley, Upper Saddle River.

Budynas, R.G., and Nısbett, J.K, 2011. Shigley's Mechanical Engineering Design, P: 4-10.

Damıan, D.D., and Dermıtzakıs, K., 2010. Morphological Design for a Prosthetic Hand: Bone Curvature and Ridged Skin. Artificial Intelligence Laboratory, University of Zurich, Switzerland.

Fargnolı, M., Rovıda, E., and Troısı, R., 2006. The Morphological Matrix: Tool for the Development of Innovative Design Solutions. The University of Tokyo, Japan, Politecnico di Milano, Italy, University of Rome "La Sapienza", Italy.

Gero, J.S., and Kannengiesser, U., 2006. The Situated Function–Behaviour–Structure Framework. Key Centre of Design Computing and Cognition, University of Sydney, Australia.

Gero, J.S., Pourmohamadı, M., and Wıllıams, C.B., 2012. The Effect of Employing Different Design Methods on the Design Cognition of Small Design Teams. Krasnow Institute for Advanced Studies, USA, University of Sydney, Australia, and Virginia Polytechnic Institute and State University, USA.

Haık, Y., and Şahin, T., 2011. Engineering Design Process. University of North Carolina, US, and Kings College London, UK.

Hatchuel, A., Le Masson, P., and Weıl, B., 2004. C-K Theory in Practice: Lessons from Industrial Applications. International Design Conference, Dubrovnik.

Hatchuel, A., Le Masson, P., and Weıl, B., 2005. The Development of Science-Based Products: Managing by Design Spaces. Creativity and Innovation Management. P: 345-354.

Kroll, E., 2012. Design Theory and Conceptual Design: Contrasting Functional Decomposition and Morphology with Parameter Analysis.

Kurtoğlu, T., and Campbell, M.I., 2009. Automated Synthesis of Electromechanical Design Configurations from Empirical Analysis of Function to Form Mapping. Automated Design Lab Department of Mechanical Engineering University of Texas at Austin, Texas.

Ostertag, O., Ostertagova, E., and Hunady, R., 2012. Morphological Matrix Applied within the Design Project of the Manipulator Frame. Technical University of Košice, Slovak Republic.

Ostertag, O., Ostertagova, E., Kovac, J., and Malega, P., 2012. Application of Morphological Analysis in the Design of Production Systems. Technical University of Košice, Slovak Republic.

Ostertagova, E., Kovac, J., and Malega, P., 2011. Application of Morphological Analysis by Selection of Material Flow Structure and Storage Allocation to Production System. Technical University of Košice, Slovak Republic. The 4th International Modelling of Mechanical and Mechatronic Systems Conference. Herany, Slovak Republic.

Rıchardson, J.L., Summers, J.D., and Mocko, G.M., 2011. Function Representations in Morphological Charts: An Experimental Study on Variety and Novelty on Means Generated. In: Interdisciplinary Design: Proceedings of the 21st CIRP Design Conference.

Rıtchey, T., 1998. General Morphological Analysis - A General Method for Non-Quantified Modelling. 16th EURO Conference on Operational Analysis, Brussels.

Sarigül, Ç., 2014. Developing Generic Systematic Approach for the Conceptual Design of Flexible Manufacturing Cells, Interim PhD Report.

Smıth, G., Rıchardson, J., Summers, J. D., and Mocko, G. M. (2012). Concept Exploration through Morphological Charts: An Experimental Study. Journal of Mechanical Design.

Summers, J. D., 2008. Objective Tree. Mechanical Engineering Department, Clemson University.

Weber, R.G., and Condoor, S.S., 1998. Conceptual Design Using a Synergistically Compatible Morphological Matrix. BEI School of Engineering Fairfield University, Fairfield, Department of Aerospace & Mechanical Engineering Parks College of Saint Louis University Saint Louis.

Zaharis, N., Kourtesis, D., Inzesiloglou, G., and Bibikas, D., 2011. New Product Development (NPD) Guide.

CURRICULUM VITAE

Mehmet Mert KAVUZLU was born in Seyhan/Adana in 1985. He graduated from Çukurova University as mechanical engineer in 2011.

After he has completed his military service in 2011, he started to work in BOSSA company as project engineer. He was responsible R&D projects in 2014, He started to work as mechanical engineer in Güney Çelik A.Ş. which is iron and steel plant responsible for R&D projects.

APPENDIX - A

1. MORPHOLOGICAL DESIGN APPLICATION for MECHANICAL FRUIT PRESS DESIGN

The expectations of the mechanical fruit press users obtain as;

- Low cost
- Low weight
- Corrosion resistance
- Less sliding
- Comfortable handling
- Easily removable
- Good press ability
- Sieve
- Ease of use

The designers' should design the mechanical fruit press in consideration of these requirements which listed in Table 1. There are some operational necessities to get these properties are;

- Base
- Pressing
- Support
- Sieving
- Carafe

Now, morphological matrix can be created based upon these criteria in Table 2. As it seen, there are 32 different product designs may generate.

Table 1. Requirement list for the mechanical fruit press

	The requirements list for mechanical fruit press		
	D:Demand W: Wish	Requirements	
	D (100%)	Corrosion Resistance	
	D (100%)	Cost of product < 20€	
	W (%3)	Low cost	
	W (%5)	Low weight	
	W (92%)	**Technical Properties:**	
		Body	
	W (25%)	Less sliding	
		Pressing	
	W (15%)	Good press ability	
		Support	
	W (13%)	Comfortable handling	
	W (4%)	Easily removable	
		Sieving	
	W (23%)	Low diameter hole	
	D (100%)	Hole dimeter < 10 mm	
		Carafe	
	W (20%)	Ease of use	

Table 2. Morphological matrix design specification alternatives for the mechanical fruit press

Alternatives / Function	**1**	**2**	**3**	**4**
Body	Free standing monoblock	Free standing pronged	Lockable monoblock	Lockable pronged
Pressing	Upside and Monoblock	Side & Horizontal Handle	Upside and Pronged	Side & Vertical Handle
Support	Handle			
Sieving	Sieve			
Carafe	Carafe with sieve	Carafe without sieve		

All of these 32 alternatives are shown in Table 16 in appendix. First evaluation method is the selection chart for demands which shown in Table 3.

Table 3. Selection chart of the mechanical fruit press

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	DECISION
V_1	+	+	+	+	+	+	?		
V_2	-	+	+	+	?	+	+		
V_3	+	+	+	+	+	?	+		
V_4	+	+	+	+	-	?	+		
V_5	-	+	+	+	?	-	?		
V_6	+	+	+	-	+	+	?		
V_7	-	+	+	+	-	+	?		
V_8	+	+	+	-	-	+	?		
V_9	+	-	+	+	?	+	?		
V_{10}	+	+	+	-	+	-	+		
V_{11}	-	+	-	+	+	+	?		
V_{12}	+	+	+	-	+	?	+		
V_{13}	+	-	+	+	?	-	?		
V_{14}	+	-	+	+	-	-	+		
V_{15}	+	+	-	-	-	?	?		
V_{16}	+	-	+	+	+	-	?		
V_{17}	+	+	-	+	-	-	+		
V_{18}	+	+	-	+	-	-	?		
V_{19}	-	+	+	+	-	?	+		
V_{20}	+	+	-	+	-	-	?		
V_{21}	+	-	+	+	?	+	?		
V_{22}	+	-	+	+	+	-	?		
V_{23}	-	+	+	+	+	-	?		
V_{24}	+	+	+	-	+	-	+		
V_{25}	+	+	+	-	+	+	?		
V_{26}	+	+	+	-	+	+	?		
V_{27}	+	-	+	+	+	+	+		
V_{28}	-	+	+	+	+	-	+		
V_{29}	+	+	+	-	-	-	+		
V_{30}	-	+	+	+	+	-	?		
V_{31}	+	-	+	+	+	?	?		
V_{32}	+	+	-	+	?	+	+		

After the detection of design alternatives which fulfil demands parameters, weighted objective tree (WOT) evaluation method which is shown in Table 4 is implemented according to wishes parameters. Then, evaluation chart which is shown in Table 5 was created to decide the best design.

Table 4. WOT evaluation technique for the mechanical fruit press

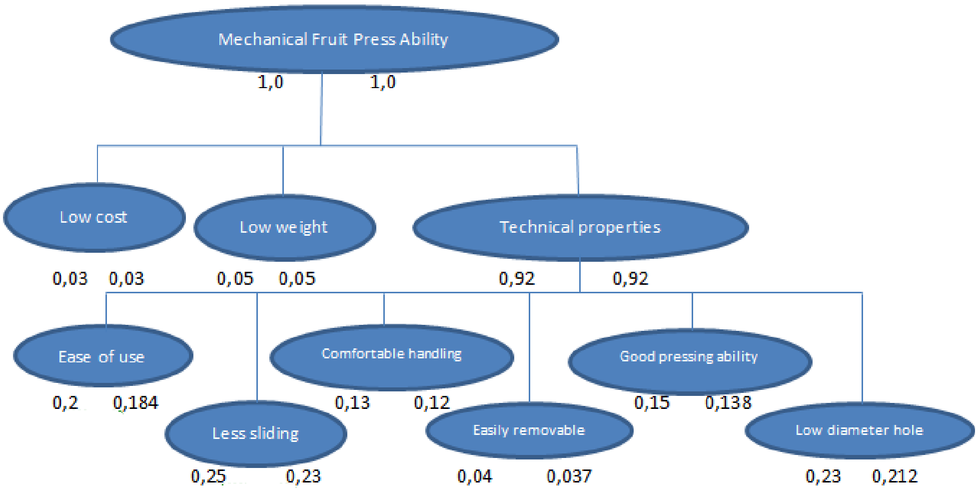


Table 5. Evaluation chart of the mechanical fruit press

			V_1		V_3		V_4	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.03	3	0.09	2	0.06	2	0.06
2	Low weight	0.05	3	0.15	3	0.15	3	0.15
3	Ease of use	0,184	4	0.736	3	0.552	2	0.368
4	Less sliding	0.23	4	0.92	2	0.46	2	0.46
5	Comfortable handlıng	0.12	3	0.36	2	0.24	2	0.24
6	Easily removable	0.037	2	0.074	2	0.074	2	0.074
7	Good press ability	0.138	4	0.552	3	0.414	3	0.414
8	Low diameter hole	0.212	3	0.636	3	0.636	3	0.636
		$\sum$Wt.=1		**$\sum$OWV$_1$= 3.518**		$\sum$OWV$_3$= 2.586		$\sum$OWV$_4$= 2.402

Table 6. Morphological matrix of all design alternatives for the mechanical fruit press

Carafe	Sieving	Support	Pressing	Body	Function / Alternatives
Carafe with sieve	Sieve	Handle	Side & Horizontal Handle	Free standing monoblock	1
Carafe with sieve	Sieve	Handle	Upside & Monoblock	Free standing monoblock	2
Carafe with sieve	Sieve	Handle	Side & Vertical Handle	Free standing pronged	3
Carafe without sieve	Sieve	Handle	Side & Vertical Handle	Free standing monoblock	4
Carafe with sieve	Sieve	Handle	Upside & Prolonged	Free standing monoblock	5
Carafe without sieve	Sieve	Handle	Upside & Monoblock	Free standing monoblock	6
Carafe with sieve	Sieve	Handle	Upside & Prolonged	Free standing pronged	7
Carafe without sieve	Sieve	Handle	Upside & Monoblock	Free standing pronged	8
Carafe with sieve	Sieve	Handle	Side & Vertical Handle	Free standing monoblock	9
Carafe without sieve	Sieve	Handle	Upside & Prolonged	Free standing pronged	10
Carafe with sieve	Sieve	Handle	Upside & Monoblock	Lockable monoblock	11
Carafe without sieve	Sieve	Handle	Upside & Prolonged	Lockable pronged	12
Carafe without sieve	Sieve	Handle	Side & Horizontal Handle	Free standing monoblock	13
Carafe without sieve	Sieve	Handle	Upside & Prolonged	Free standing monoblock	14
Carafe with sieve	Sieve	Handle	Upside & Prolonged	Lockable pronged	15
Carafe without sieve	Sieve	Handle	Side & Horizontal Handle	Free standing monoblock	16
Carafe without sieve	Sieve	Handle	Side & Vertical Handle	Free standing monoblock	17

Table 6. Morphological matrix of all design alternatives for the mechanical fruit press (Continue)

Carafe	Sieving	Support	Pressing	Body	Function / Alternatives
Carafe with sieve	Sieve	Handle	Upside & Monoblock	Free standing pronged	20
Carafe with sieve	Sieve	Handle	Side & Horizontal Handle	Free standing pronged	21
Carafe with sieve	Sieve	Handle	Upside & Monoblock	Lockable pronged	22
Carafe without sieve	Sieve	Handle	Side & Horizontal Handle	Lockable monoblock	23
Carafe with sieve	Sieve	Handle	Side & Horizontal Handle	Lockable monoblock	24
Carafe without sieve	Sieve	Handle	Side & Vertical Handle	Lockable monoblock	25
Carafe with sieve	Sieve	Handle	Side & Vertical Handle	Lockable monoblock	26
Carafe with sieve	Sieve	Handle	Upside & Monoblock	Lockable monoblock	27
Carafe without sieve	Sieve	Handle	Upside & Monoblock	Lockable pronged	28
Carafe without sieve	Sieve	Handle	Side & Horizontal Handle	Lockable pronged	29
Carafe with sieve	Sieve	Handle	Side & Vertical Handle	Lockable pronged	30
Carafe without sieve	Sieve	Handle	Side & Horizontal Handle	Lockable pronged	31
Carafe with sieve	Sieve	Handle	Side & Vertical Handle	Lockable pronged	32

2. MORPHOLOGICAL DESIGN APPLICATION for MECHANICAL PENCIL DESIGN

The expectations of the mechanical pencil users obtain as;

- Low cost
- Less lead fracture
- Non-rolling body
- Steady lead
- Clean-living eraser
- Anti-skid grip
- Non-destructive grip
- Easily portable

The designers should design the mechanical pencil in consideration of these requirements which are shown in Table 7. There are some operational necessities to get these properties are;

- Body
- Grip type
- Cone cap
- Eraser

After the creation our morphological matrix table as shown in Table 8, there are 36 different design specifications mechanical pencil may developed as shown in Table 12.

Table 7. Requirement list for the mechanical pencil

The requirements list for mechanical pencil	
D: Demand W: Wish	Requirements
D (100%)	Cost of product < 10€
W (10%)	Low cost
W (90%)	**Technical Properties:**
	Body
W (40%)	Non-rolling
D (100%)	Easily portable
	Grip Type
W (5%)	Anti-skid
W (10%)	Non-destructive
	Con Cap
W (15%)	Prevent lead fracture
W (10%)	Steady lead
	Eraser
W (20%)	Clean-living

Table 8. Morphological matrix for design specification alternatives for the mechanical pencil

Alternatives / **Function**	**1**	**2**	**3**
Body	Hexagonal body with clips	Circular body with clips	Triangle body with clips
Grip Type	Rubber	Groove	Rubber & Groove
Cone Cap	Penetration & Lead Holder	Constant & Lead Holder	
Eraser	Rotational	Covered	

All of these 36 different mechanical pencil alternatives are shown in Table 17 in appendix. First evaluation method of morphological design is the selection chart for demands which shown in Table 9.

Table 9. Selection chart of the mechanical pencil

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	DECISION
V_1	+	+	+	-	-	+	?		
V_2	-	+	+	+	?	-	+		
V_3	+	+	+	+	+	+	?		
V_4	+	+	-	+	-	?	+		
V_5	-	+	+	+	-	-	?		
V_6	+	+	+	+	+	-	?		
V_7	-	+	+	+	-	-	?		
V_8	+	+	+	-	+	+	?		
V_9	+	-	+	+	-	+	?		
V_{10}	+	+	+	-	?	-	+		
V_{11}	-	+	-	+	-	+	?		
V_{12}	+	+	+	-	+	-	+		
V_{13}	+	+	+	+	-	-	?		
V_{14}	+	-	+	+	+	-	+		
V_{15}	+	+	-	-	-	?	?		
V_{16}	+	-	+	+	+	-	+		
V_{17}	+	+	-	+	-	-	?		
V_{18}	+	+	+	+	-	+	?		
V_{19}	-	+	+	+	-	-	+		
V_{20}	+	+	-	+	+	-	?		
V_{21}	+	-	+	+	-	+	?		
V_{22}	+	-	+	+	+	-	+		
V_{23}	-	+	+	+	-	-	?		
V_{24}	+	+	+	+	+	+	+		
V_{25}	+	+	-	+	+	+	?		
V_{26}	+	+	+	-	+	-	?		
V_{27}	+	-	+	+	+	?	+		
V_{28}	-	+	+	+	+	-	?		
V_{29}	+	+	+	-	+	-	+		
V_{30}	-	+	+	+	-	-	?		
V_{31}	+	-	+	+	+	-	?		
V_{32}	+	+	-	+	-	+	+		
V_{33}	+	+	-	+	-	+	?		
V_{34}	+	+	-	+	+	-	?		
V_{35}	+	+	-	+	-	-	?		
V_{36}	+	-	+	-	+	-	?		

After the detection of design alternatives which fulfil demands parameters, weighted objective tree (WOT) evaluation method which is shown in Table 10 is implemented according to wishes parameters. Then, evaluation chart which is shown in Table 11 was created to decide the best design.

Table 10. WOT evaluation technique for the mechanical pencil

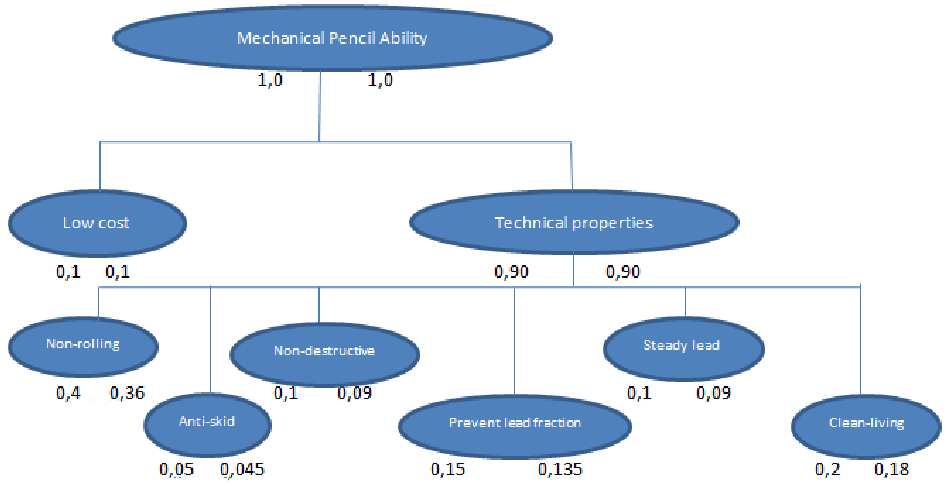


Table 11. Evaluation chart of the mechanical pencil

			V_3		V_6		V_{13}		V_{18}		V_{24}	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.1	3	0.3	3	0.3	2	0.2	2	0.2	2	0.2
2	Non-rolling	0.36	4	1.44	4	1.44	2	0.72	2	0.72	2	0.72
3	Anti-skid	0.045	4	0.18	4	0.18	4	0.18	2	0.09	3	0.135
4	Non-destructive	0.09	4	0.36	3	0.27	4	0.36	3	0.27	4	0.36
5	Prevent lead fraction	0.135	4	0.54	3	0.405	4	0.54	3	0.405	3	0.405
6	Steady lead	0.09	4	0.36	4	0.36	4	0.36	4	0.36	4	0.36
7	Clean-living	0.18	3	0.54	3	0.54	3	0.54	3	0.54	4	0.72
		$\sum Wt. = 1$		$\sum OWV_3 = 3.72$		$\sum OWV_6 = 3.495$		$\sum OWV_{13} = 2.9$		$\sum OWV_{18} = 2.585$		$\sum OWV_{24} = 2.9$

Table 12. Morphological matrix of all design alternatives for the mechanical pencil

Eraser	Cone Cap	Grip Type	Body	Function / Alternatives
Rotational	Constant & Lead Holder	Rubber	Hexagonal body with clips	1
Covered	Penetration & Lead Holder	Rubber	Hexagonal body with clips	2
Rotational	Penetration & Lead Holder	Rubber	Hexagonal body with clips	3
Covered	Constant & Lead Holder	Rubber	Hexagonal body with clips	4
Rotational	Penetration & Lead Holder	Groove	Hexagonal body with clips	5
Rotational	Constant & Lead Holder	Groove	Hexagonal body with clips	6
Covered	Penetration & Lead Holder	Groove	Hexagonal body with clips	7
Covered	Constant & Lead Holder	Groove	Hexagonal body with clips	8
Rotational	Penetration & Lead Holder	Rubber & Groove	Hexagonal body with clips	9
Covered	Penetration & Lead Holder	Rubber & Groove	Hexagonal body with clips	10
Rotational	Constant & Lead Holder	Rubber & Groove	Hexagonal body with clips	11
Covered	Constant & Lead Holder	Rubber & Groove	Hexagonal body with clips	12
Rotational	Penetration & Lead Holder	Rubber	Circular body with clips	13
Covered	Penetration & Lead Holder	Rubber	Circular body with clips	14
Rotational	Constant & Lead Holder	Rubber	Circular body with clips	15
Covered	Constant & Lead Holder	Rubber	Circular body with clips	16
Rotational	Penetration & Lead Holder	Groove	Circular body with clips	17
Rotational	Constant & Lead Holder	Groove	Circular body with clips	18
Covered	Penetration & Lead Holder	Groove	Circular body with clips	19

Table 12. Morphological matrix of all design alternatives for the mechanical pencil (Continue)

Eraser	Cone Cap	Grip Type	Body	Function / Alternatives
Covered	Constant & Lead Holder	Groove	Circular body with clips	20
Rotational	Penetration & Lead Holder	Rubber & Groove	Circular body with clips	21
Covered	Penetration & Lead Holder	Rubber & Groove	Circular body with clips	22
Rotational	Constant & Lead Holder	Rubber & Groove	Circular body with clips	23
Covered	Constant & Lead Holder	Rubber & Groove	Circular body with clips	24
Rotational	Penetration & Lead Holder	Rubber	Triangle body with clips	25
Covered	Penetration & Lead Holder	Rubber	Triangle body with clips	26
Rotational	Constant & Lead Holder	Rubber	Triangle body with clips	27
Covered	Constant & Lead Holder	Rubber	Triangle body with clips	28
Rotational	Penetration & Lead Holder	Groove	Triangle body with clips	29
Rotational	Constant & Lead Holder	Groove	Triangle body with clips	30
Covered	Penetration & Lead Holder	Groove	Triangle body with clips	31
Covered	Constant & Lead Holder	Groove	Triangle body with clips	32
Rotational	Penetration & Lead Holder	Rubber & Groove	Triangle body with clips	33
Covered	Penetration & Lead Holder	Rubber & Groove	Triangle body with clips	34
Rotational	Constant & Lead Holder	Rubber & Groove	Triangle body with clips	35
Covered	Constant & Lead Holder	Rubber & Groove	Triangle body with clips	36

3. MORPHOLOGICAL DESIGN APPLICATION for MANIPULATOR FRAME DESIGN

The expectations of the frame users obtain as;

- Ease of assemblability
- Manufacturability
- Cost
- Durability
- Corrosion resistance
- Ease of use
- Balanced
- High strength
- Perpetuity connection

The designers should design the manipulator frame in consideration of these requirements which are shown in Table 13.There are some operational necessities to get these properties are;

- Beam cross-section type
- Beam fabrication
- Body cross-section type
- Body fabrication
- Beam and body connection
- Conveyance mode

Now, we can create our morphological matrix table for manipulator frame specification alternatives in Table 14.

Table 13. Requirement list for the mechanical pencil

	The requirements list for manipulator frame		
	D: Demand W: Wish	Requirements	
	D (100%) D (100%) W (15%) **W (85%)** W (20%) D (100%) W (15%) W (20%) D (100%) W (15%) W (20%) W (10%)	Cost of product < 50€ Corrosion resistance Low cost **<u>Technical Properties:</u>** **Beam Cross-section Type** Durability Ease of assemblability **Beam Fabrication Technology** High strength **Body Cross-section Type** Balanced Ease of assemblability **Body Fabrication Technology** Manufacturability **Beam & Body Connection** Perpetuity connection **Conveyance Mode** Ease of use	

Table 14. Morphological matrix of design specification alternatives for the frame design

Function \ Alternatives	1	2	3
Beam Cross-section Shape	Open 2xL	Closed 2xU	Open H
Beam Fabrication Technology	Cast	Drawn	
Body Cross-section Shape	Rectangular	Round	
Body Fabrication Technology	Cast	Drawn	
Beam and Body Connection	Weld		
Conveyance Mode	Basket	Hook	

All of these 48 different manipulator frame alternatives are shown in Table 18 in appendix. First evaluation method of morphological design is the selection chart for demands which shown in Table 15.

Table 15. Selection chart of the manipulator frame

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	Decision
V_1	+	+	-	+	-	+	?		
V_2	+	-	+	+	?	-	+		
V_3	+	-	+	+	+	?	+		
V_4	+	+	+	+	-	?	+		
V_5	-	+	+	+	-	-	?		
V_6	+	+	+	-	+	-	?		
V_7	+	+	+	-	-	-	?		
V_8	-	+	+	+	+	+	?		
V_9	-	+	+	+	-	+	?		
V_{10}	+	-	+	-	?	-	+		
V_{11}	+	+	-	+	-	+	?		
V_{12}	+	+	+	-	+	-	+		
V_{13}	-	+	+	+	-	-	?		
V_{14}	+	+	+	-	+	-	+		
V_{15}	+	+	-	+	-	?	?		
V_{16}	+	+	+	-	+	-	+		
V_{17}	-	+	+	+	-	-	?		
V_{18}	+	-	+	+	-	+	?		
V_{19}	+	+	-	+	-	-	+		
V_{20}	+	+	+	-	+	-	?		
V_{21}	-	+	+	+	-	+	?		
V_{22}	+	+	+	-	+	-	+		
V_{23}	-	+	+	+	-	-	?		
V_{24}	+	+	+	-	+	+	+		
V_{25}	-	+	+	+	+	?	+		
V_{26}	+	+	+	-	+	-	?		
V_{27}	+	+	+	+	+	?	+		
V_{28}	+	+	+	-	+	-	?		
V_{29}	+	+	+	-	+	+	+		
V_{30}	-	+	-	+	-	-	?		
V_{31}	+	-	+	+	-	-	?		
V_{32}	+	+	-	+	-	?	+		
V_{33}	+	+	+	+	-	+	?		
V_{34}	+	+	-	+	+	+	?		
V_{35}	+	+	-	-	-	-	?		
V_{36}	+	-	+	+	+	-	?		
V_{37}	+	+	+	?	-	+	?		
V_{38}	+	-	+	+	+	-	+		
V_{39}	+	+	-	+	?	+	?		
V_{40}	+	+	+	-	+	?	+		
V_{41}	+	+	+	-	-	-	?		
V_{42}	+	-	+	?	+	-	+		
V_{43}	+	+	-	+	-	?	+		
V_{44}	+	+	+	-	+	-	?		
V_{45}	-	+	+	+	-	?	?		
V_{46}	+	+	+	-	-	+	?		
V_{47}	+	+	?	+	-	-	+		
V_{48}	+	+	-	-	+	-	?		

After the detection of design alternatives which fulfil demands parameters, weighted objective tree (WOT) evaluation method which is shown in Table 16 is implemented according to wishes parameters. Then, evaluation chart which is shown in Table 17 was created to decide the best design.

Table 16. WOT evaluation technique for the manipulator frame

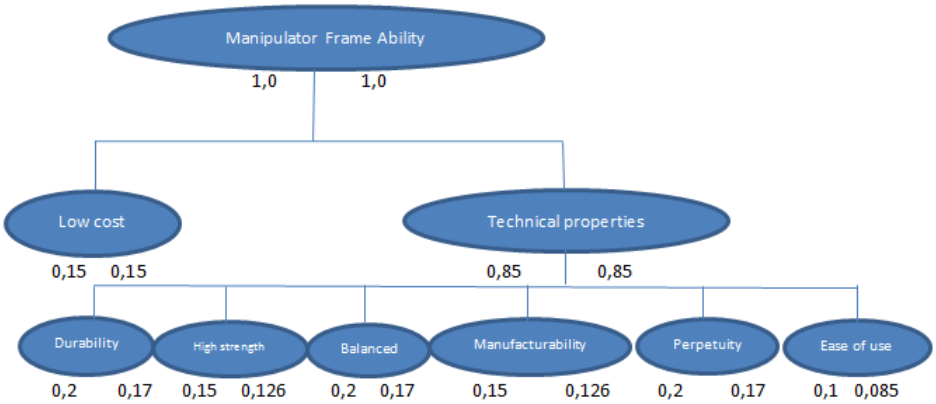


Table 17. Evaluation chart of the manipulator frame

			V_4		V_{25}		V_{27}		V_{33}	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low cost	0.15	3	0.45	2	0.3	3	0.45	2	0.3
2	Durability	0.17	3	0.51	3	0.51	3	0.51	2	0.34
3	High strength	0.126	3	0.378	3	0.378	4	0.504	3	0.378
4	Balanced	0.17	4	0.68	4	0.68	4	0.68	4	0.68
5	Manufacturability	0.126	3	0.378	4	0.504	3	0.378	4	0.504
6	Perpetuity	0.17	4	0.68	4	0.68	4	0.68	4	0.68
7	Ease of use	0.085	3	0.255	4	0.34	4	0.34	4	0.34
		$\sum$Wt. =1		$\sum OWV_4$= 3.331		$\sum OWV_{25}$ = 3.392		**$\sum OWV_{27}$ = 3.542**		$\sum OWV_{33}$ = 3.222

Table 18. Morphological matrix of all design alternatives for the manipulator frame design

Conveyance Mode	Beam and Body Connection	Body Fabrication Technology	Body Cross-section Type	Beam Fabrication Technology	Beam Cross-section Type	Function / Alternatives
Closed Basket	Weld	Cast	Rectangular	Cast	Open 2xL	1
Perforated Basket	Weld	Cast	Rectangular	Cast	Open 2xL	2
Closed Basket	Weld	Drawn	Rectangular	Cast	Open 2xL	3
Perforated Basket	Weld	Drawn	Rectangular	Cast	Open 2xL	4
Closed Basket	Weld	Cast	Round	Cast	Open 2xL	5
Perforated Basket	Weld	Cast	Round	Cast	Open 2xL	6
Closed Basket	Weld	Drawn	Round	Cast	Open 2xL	7
Perforated Basket	Weld	Drawn	Round	Cast	Open 2xL	8
Closed Basket	Weld	Cast	Rectangular	Drawn	Open 2xL	9
Perforated Basket	Weld	Cast	Rectangular	Drawn	Open 2xL	10
Closed Basket	Weld	Drawn	Rectangular	Drawn	Open 2xL	11
Perforated Basket	Weld	Drawn	Rectangular	Drawn	Open 2xL	12
Closed Basket	Weld	Cast	Round	Drawn	Open 2xL	13
Perforated Basket	Weld	Cast	Round	Drawn	Open 2xL	14
Closed Basket	Weld	Drawn	Round	Drawn	Open 2xL	15
Perforated Basket	Weld	Drawn	Round	Drawn	Open 2xL	16
Closed Basket	Weld	Cast	Rectangular	Cast	Closed 2xU	17
Perforated Basket	Weld	Cast	Rectangular	Cast	Closed 2xU	18
Closed Basket	Weld	Drawn	Rectangular	Cast	Closed 2xU	19

Table 18. Morphological matrix of all design alternatives for the manipulator frame design (Continue)

Conveyance Mode	Beam and Body Connection	Body Fabrication Technology	Body Cross-section Type	Beam Fabrication Technology	Beam Cross-section Type	Function / Alternatives
Perforated Basket	Weld	Drawn	Rectangular	Cast	Closed 2xU	20
Closed Basket	Weld	Cast	Round	Cast	Closed 2xU	21
Perforated Basket	Weld	Cast	Round	Cast	Closed 2xU	22
Closed Basket	Weld	Drawn	Round	Cast	Closed 2xU	23
Perforated Basket	Weld	Drawn	Round	Cast	Closed 2xU	24
Closed Basket	Weld	Cast	Rectangular	Drawn	Closed 2xU	25
Perforated Basket	Weld	Cast	Rectangular	Drawn	Closed 2xU	26
Closed Basket	Weld	Drawn	Rectangular	Drawn	Closed 2xU	27
Perforated Basket	Weld	Drawn	Rectangular	Drawn	Closed 2xU	28
Closed Basket	Weld	Cast	Round	Drawn	Closed 2xU	29
Perforated Basket	Weld	Cast	Round	Drawn	Closed 2xU	30
Closed Basket	Weld	Drawn	Round	Drawn	Closed 2xU	31
Perforated Basket	Weld	Drawn	Round	Drawn	Closed 2xU	32
Closed Basket	Weld	Cast	Rectangular	Cast	Open H	33
Perforated Basket	Weld	Cast	Rectangular	Cast	Open H	34
Closed Basket	Weld	Drawn	Rectangular	Cast	Open H	35
Perforated Basket	Weld	Drawn	Rectangular	Cast	Open H	36
Closed Basket	Weld	Cast	Round	Cast	Open H	39
Perforated Basket	Weld	Cast	Round	Cast	Open H	40
Closed Basket	Weld	Drawn	Round	Cast	Open H	41
Perforated Basket	Weld	Drawn	Round	Cast	Open H	42
Closed Basket	Weld	Cast	Rectangular	Drawn	Open H	43
Perforated Basket	Weld	Cast	Rectangular	Drawn	Open H	44
Closed Basket	Weld	Drawn	Rectangular	Drawn	Open H	45
Perforated Basket	Weld	Drawn	Rectangular	Drawn	Open H	46
Closed Basket	Weld	Cast	Round	Drawn	Open H	47
Perforated Basket	Weld	Cast	Round	Drawn	Open H	48

APPENDIX - B

1. THE NEW APPROACH to SYSTEMATIC DESIGN APPLICATION for MECHANICAL FRUIT PRESS

Table 19. Requirement list of the mechanical fruit press

	The requirements list for mechanical fruit press		
	D: Demand W: Wish	Requirements	
	D (100%)	Corrosion Resistance	
	D (100%)	Cost of product < 20€	
	D (100%)	Hole dimeter < 10 mm	
		Technical Properties:	
		Body	
	W (30%)	Less sliding	
	W (30%)	Low weight	
	W (40%)	Low cost	
		Pressing	
	W (25%)	Low weight	
	W (30%)	Low cost	
	W (45%)	Good press ability	
		Support	
	W (30%)	Comfortable handling	
	W (15%)	Easily removable	
	W (25%)	Low weight	
	W (30%)	Low cost	
		Sieving	
	W (40%)	Low diameter hole	
	W (30%)	Low weight	
	W (30%)	Low cost	
		Carafe	
	W (100%)	Ease of use	

Table 20. VDI guideline evaluation technique

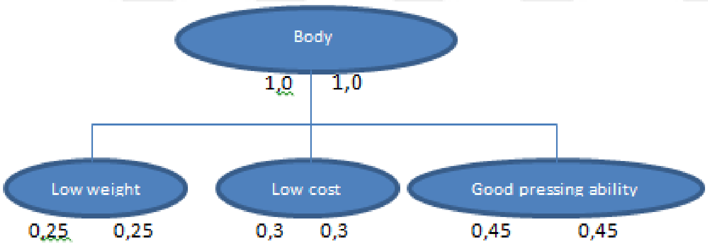
Guideline VDI 2225	
Points	Meaning
0	unsatisfactory
1	just tolerable
2	adequate
3	good
4	very good (ideal)

Table 21. The combination of VDI guideline technique and WOT analyses for technical properties of mechanical fruit press

BODY

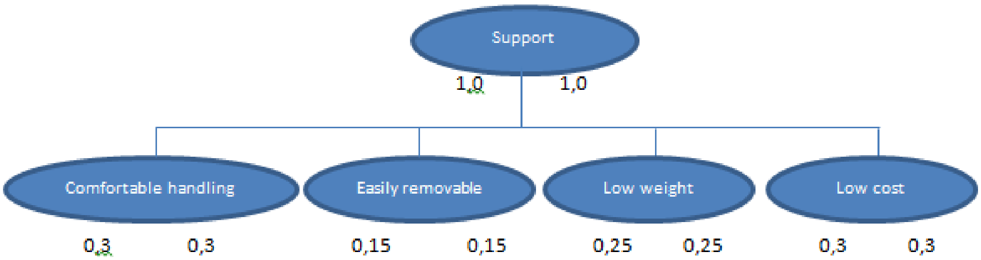
			Free standing monoblock		Free standing pronged		Lockable monoblock		Lockable pronged	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Less sliding	0.3	3	0.9	2	0.6	4	1.2	3	0.9
2	Low cost	0.4	3	1.2	2	0.8	1	0.4	0	0.0
3	Low weight	0.3	2	0.6	4	1.2	1	0.3	3	0.9
		∑Wt.=1		**∑OWV₁= 2.7**		∑OWV₂= 2.6		∑OWV₃= 1.9		∑OWV₃= 1.8

PRESSING



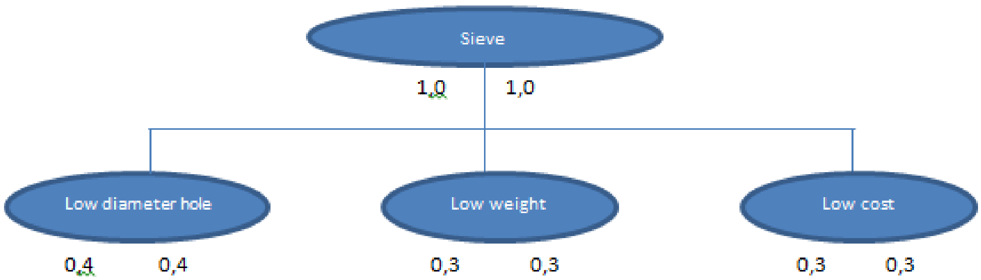
			Upside and Monoblock		Side & Horizontal Handle		Upside and Pronged		Side & Vertical Handle	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Low weight	0.25	3	0.75	2	0.5	1	0.25	3	0.75
2	Low cost	0.3	2	0.6	3	0.9	1	0.3	4	1.2
3	Good pressing ability	0.45	2	0.9	4	1.8	2	0.9	2	0.9
		∑Wt.=1		∑OWV₁= 2.25		**∑OWV₂= 3.2**		∑OWV₃= 1.45		∑OWV₃= 2.85

SUPPORT



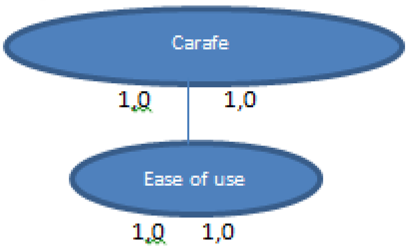
			Handle	
		Wt.	A.V.	W.V.
1	Comfortable handling	0.3	4	1.2
2	Easily removable	0.15	4	0.6
3	Low weight	0.25	4	1.0
4	Low cost	0.3	4	1.2
		∑Wt. =1		**∑OWV₁ = 4.0**

SIEVE



			Sieve	
		Wt.	A.V.	W.V.
1	Low diameter	0.4	4	1.6
2	Low weight	0.3	4	1.2
3	Low cost	0.3	4	1.2
		∑Wt.=1		**∑OWV1= 4.00**

CARAFE

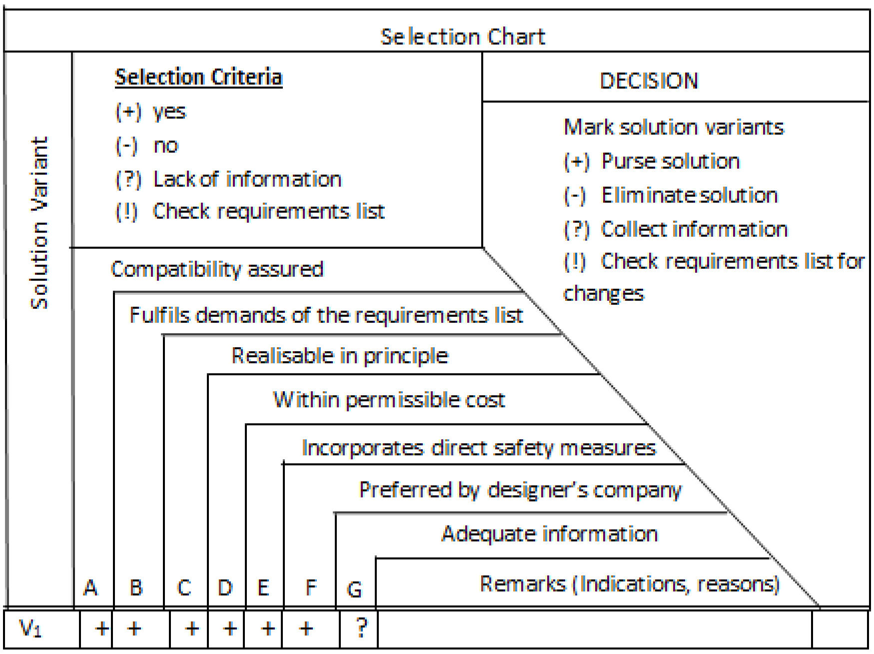


			Carafe with sieve		Carafe without sieve	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Ease of use	1.00	4	4.00	2	2.00
		∑Wt.=1		**∑OWV1= 4.00**		∑OWV2= 2.00

Table 22. General evaluation chart for mechanical fruit press

		V_1
1	**Free standing monoblock**	2.7
2	**Side& Horizontal handle**	3.2
3	**Handle**	4.0
4	**Sieve**	4.0
5	**Carafe with sieve**	4.0
		$\sum V_1 =$ **17.9**

Table 23. Selection chart for mechanical fruit press



2. THE NEW APPROACH to SYSTEMATIC DESIGN APPLICATION for MECHANICAL PENCIL

Table 24. Requirement list of the mechanical pencil

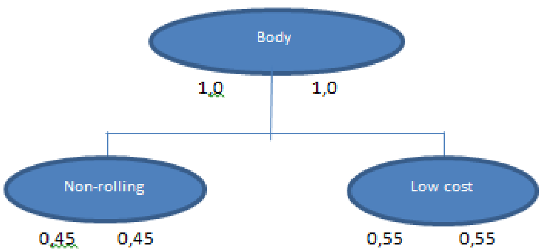
	The requirements list for mechanical pencil		
	D: Demand W: Wish	Requirements	
	D (100%)	Cost of product < 10€	
	D (100%)	Easily portable	
		<u>Technical Properties:</u>	
		Body	
	W (45%)	Non-rolling	
	W (55%)	Low cost	
		Grip Type	
	W (20%)	Anti-skid	
	W (45%)	Non-destructive	
	W (35%)	Low cost	
		Con Cap	
	W (40%)	Prevent lead fracture	
	W (40%)	Steady lead	
	W (20%)	Low cost	
		Eraser	
	W (60%)	Clean-living	
	W (40%)	Low cost	

Table 25. VDI guideline evaluation technique

Guideline VDI 2225	
Points	Meaning
0	unsatisfactory
1	just tolerable
2	adequate
3	good
4	very good (ideal)

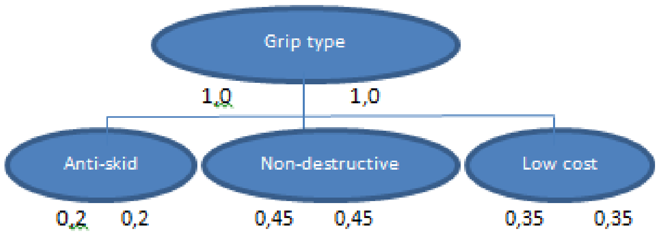
Table 26. The combination of VDI guideline technique and WOT analyses for technical properties of mechanical pencil

BODY



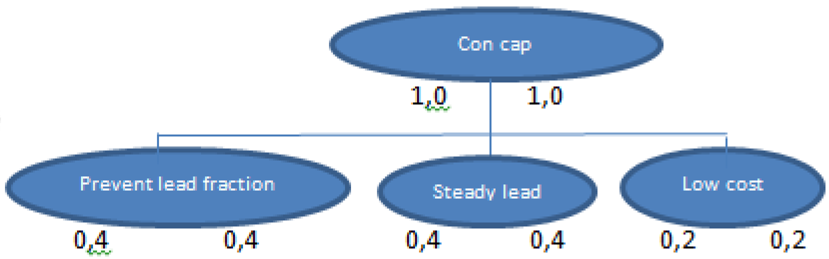
			Hexagonal body with clips		Circular body with clips		Triangle body with clips	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Non-rolling	0.45	3	1.35	2	0.9	4	1.8
2	Low cost	0.55	3	1.65	2	1.1	4	2.2
		$\sum Wt.=1$		$\sum OWV_1=$ 3.0		$\sum OWV_2=$ 2.0		**$\sum OWV_3=$ 4.0**

GRIP TYPE



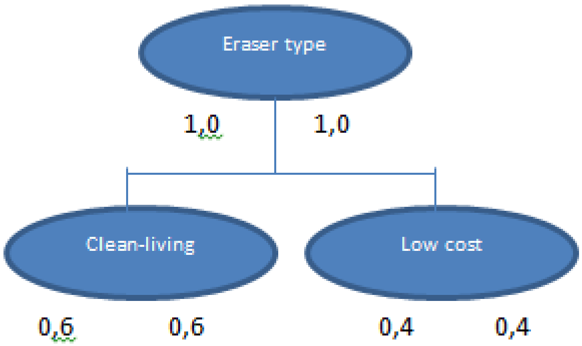
			Rubber		Groove		Rubber & Groove	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Anti-skid	0.2	3	0.6	4	0.8	3	0.6
2	Non-destructive	0.45	3	1.35	3	1.35	4	1.8
3	Low cost	0.35	4	1.40	3	1.05	2	0.7
		∑Wt.=1		**$\sum OWV_1$= 3.35**		$\sum OWV_2$= 3.2		$\sum OWV_3$= 3.1

CON CAP



			Penetration & Lead Holder		Constant & Lead Holder	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Prevent lead fraction	0.4	4	1.6	3	1.2
2	Steady lead	0.4	4	1.6	4	1.6
3	Low cost	0.2	2	0.4	3	0.6
		∑Wt.=1		**$\sum OWV_1$= 3.6**		$\sum OWV_2$= 3.4

<u>ERASER</u>



			Covered		Rotational	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Clean-living	0.6	4	2.4	4	2.4
2	Low cost	0.4	2	0.8	3	1.2
		$\sum Wt.=1$		$\sum OWV_1=$ 3.2		**$\sum OWV_2=$ 3.6**

Table 27. General evaluation chart for mechanical pencil

		V_1
1	**Triangle body with clips**	4.0
2	**Rubber**	3.35
3	**Penetration & Lead Holder**	3.6
4	**Rotational**	3.6
		$\sum V_1=$ 14.55

		V_2
1	**Hexagonal body with clips**	3.0
2	**Rubber**	3.35
3	**Penetration & Lead Holder**	3.6
4	**Rotational**	3.6
		$\sum V_2=$ 13.55

Table 28. Selection chart for mechanical pencil

Selection Chart

Selection Criteria
(+) yes
(-) no
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants
(+) Purse solution
(-) Eliminate solution
(?) Collect information
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of the requirements list
C: Realisable in principle
D: Within permissible cost
E: Incorporates direct safety measures
F: Preferred by designer's company
G: Adequate information

Solution Variant	A	B	C	D	E	F	G	Remarks (Indications, reasons)	DECISION
V_1	+	+	-	+	+	+	?		
V_2	+	+	+	+	+	+	?		

3. THE NEW APPROACH to SYSTEMATIC DESIGN APPLICATION for MANIPULATOR FRAME

Table 29. Requirement list of the manipulator frame

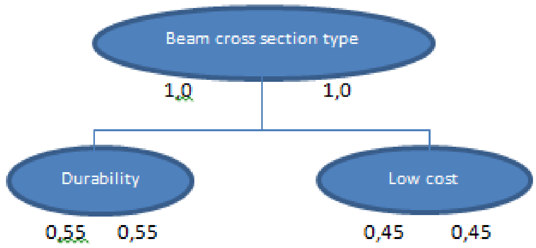
	The requirements list for manipulator frame design		
	D: Demand W: Wish	Requirements	
	D (100%)	Cost of product < 50€	
	D (100%)	Corrosion resistance	
	D (100%)	Ease of assemblability	
		<u>Technical Properties:</u>	
		Beam Cross-section Type	
	W (55%)	Durability	
	W (45%)	Low cost	
		Beam Fabrication	
	W (65%)	High strength	
	W (35%)	Low cost	
		Body Cross-section Type	
	W (60%)	Balanced	
	W (40%)	Low cost	
		Body Fabrication	
	W (65%)	Manufacturability	
	W (35%)	Low cost	
		Beam & Body Connection	
	W (70%)	Perpetuity connection	
	W (30%)	Low cost	
		Conveyance Mode	
	W (55%)	Ease of use	
	W (45%)	Low cost	

Table 30. VDI guideline evaluation technique

Guideline VDI 2225	
Points	Meaning
0	unsatisfactory
1	just tolerable
2	adequate
3	good
4	very good (ideal)

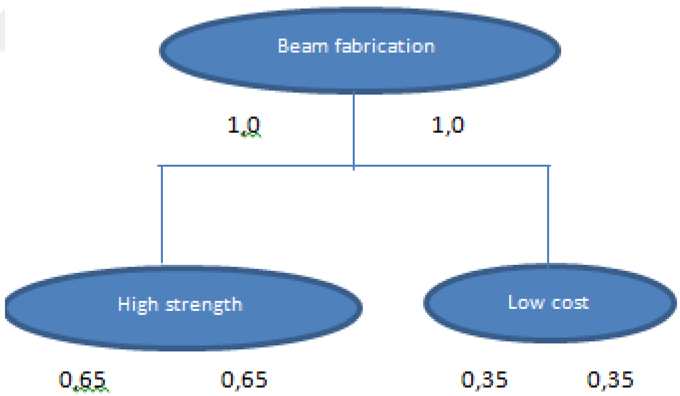
Table 31. The combination of VDI guideline technique and WOT analyses for technical properties of manipulator frame

BEAM CROSS SECTION TYPE



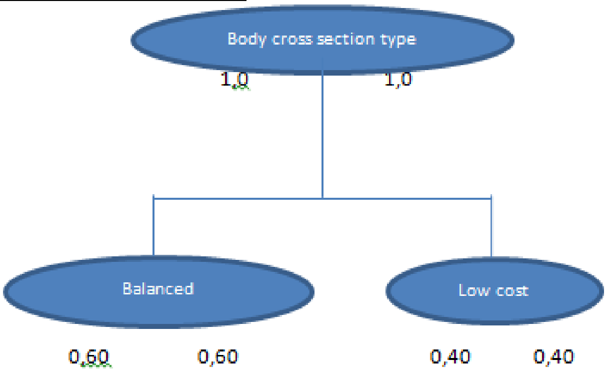
			Open 2xL		Closed 2xU		Open H	
		Wt.	A.V.	W.V.	A.V.	W.V.	A.V.	W.V.
1	Durability	0.55	3	1.65	4	2.2	2	1.1
2	Low cost	0.45	2	0.9	3	1.35	2	0.9
		∑Wt.=1		$\sum OWV_1$= 2.55		**$\sum OWV_2$= 3.55**		$\sum OWV_3$= 2.0

BEAM FABRICATION



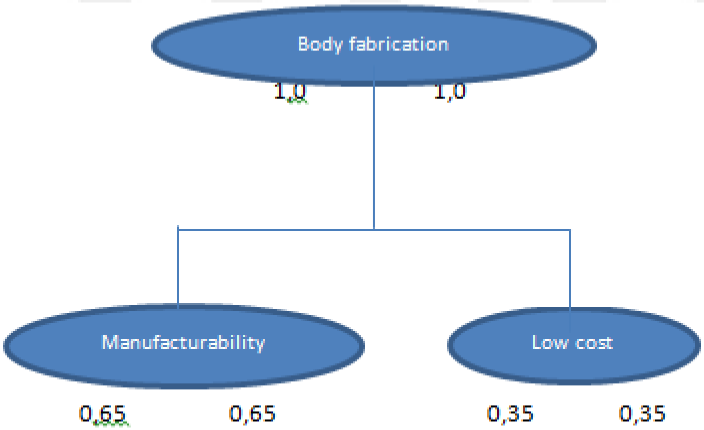
			Cast		Drawn	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	High strength	0.65	2	1.3	4	2.6
2	Low cost	0.35	4	1.4	2	0.7
		∑Wt.=1		$\sum OWV_1$= 2.7		**$\sum OWV_2$= 3.3**

BODY CROSS SECTION TYPE



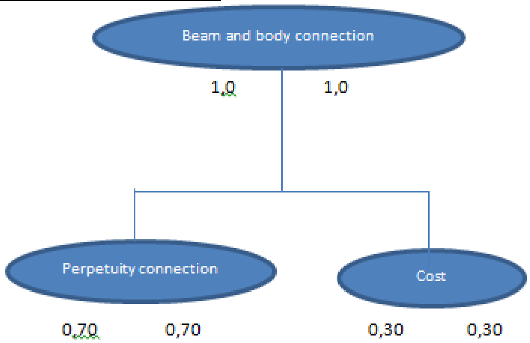
			Rectangular		Round	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Balanced	0.60	3	1.8	2	1.2
2	Low cost	0.40	3	1.2	2	0.8
		∑Wt.=1		**∑OWV₁= 3.0**		∑OWV₂= 2.0

BODY FABRICATION



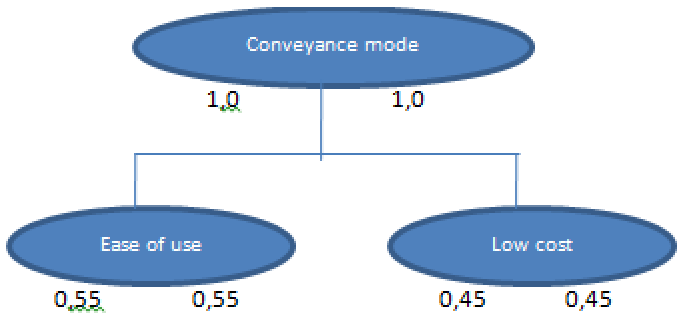
			Cast		Drawn	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Manufacturability	0.65	3	1.95	2	1.3
2	Low cost	0.35	2	0.7	3	1.05
		∑Wt.=1		**∑OWV₁= 2.65**		∑OWV₂= 2.35

BEAM AND BODY CONNECTION



			Weld	
		Wt.	A.V.	W.V.
1	Perpetuity connection	0.70	4	2.8
2	Low cost	0.30	4	1.2
		∑Wt.=1		**∑OWV₁= 4.0**

CONVEYANCE MODE

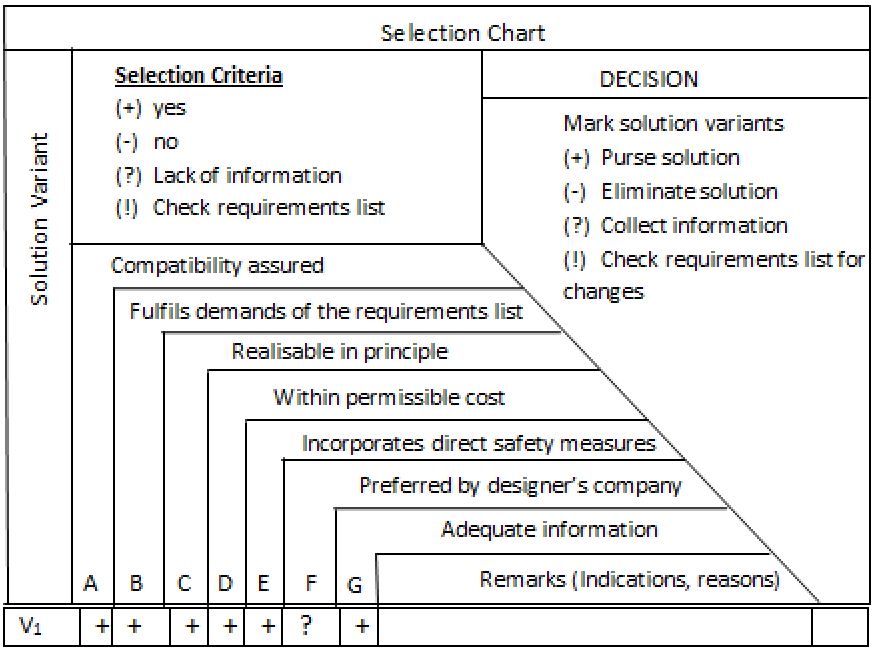


			Closed Basket		Perforated Basket	
		Wt.	A.V.	W.V.	A.V.	W.V.
1	Manufacturability	0.55	3	1.65	2	1.1
2	Low cost	0.45	2	0.9	3	0.35
		∑Wt.=1		**∑OWV₁= 2.55**		∑OWV₂= 2.45

Table 32. General evaluation chart for manipulator frame

		V_1
1	Closed 2xU	3.55
2	Drawn	3.3
3	Rectangular	3.0
4	Cast	2.65
5	Weld	4.0
6	Closed Basket	2.55
		$\sum V_1$= 19.05

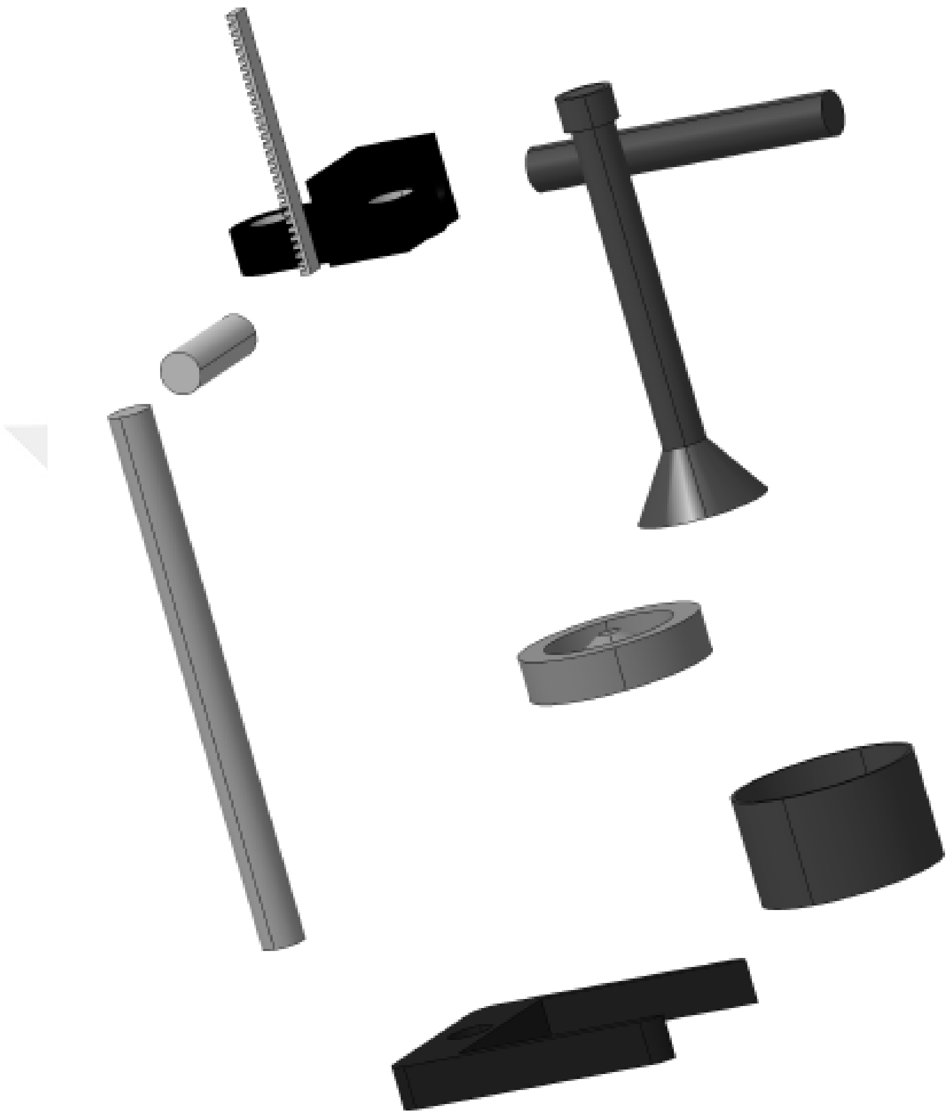
Table 33. Selection chart for frame design



APPENDIX - C

1. **THE LARGE APPEARANCE of THE MECHANICAL FRUIT PRESS**

(a)

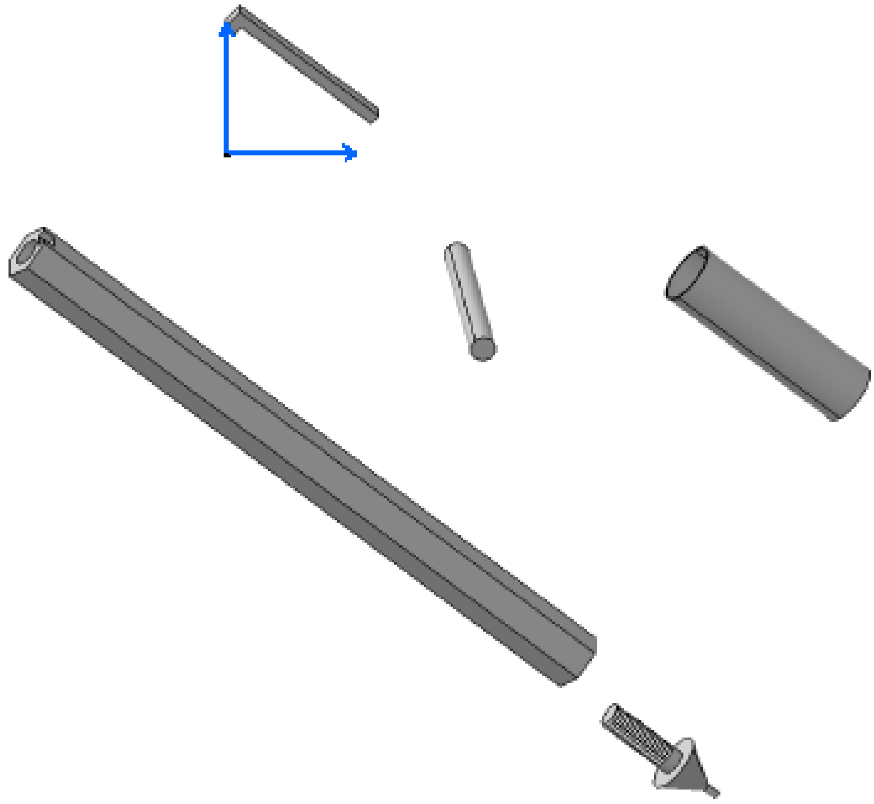


(b)

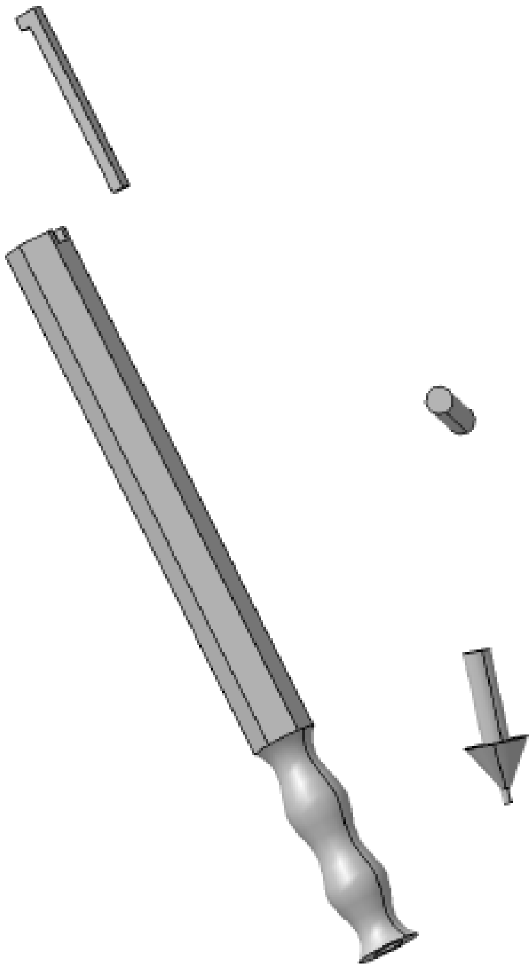
(c)

Figure 1. Assembly parts of (a) the best mechanical fruit press design alternative (b) The second best (number 3 design alternative) (c) The third best (number 4 design alternative).

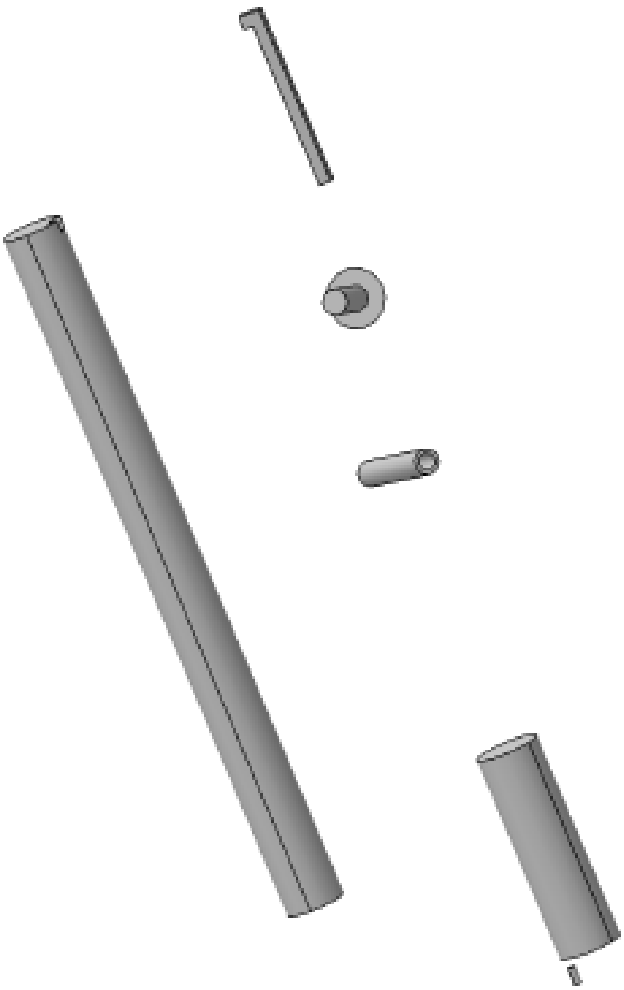
2. THE LARGE APPEARANCE of THE MECHANICAL PENCIL



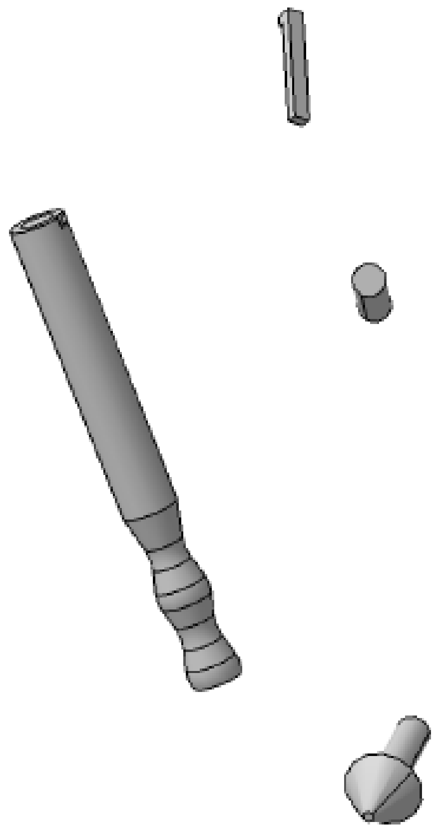
(a)



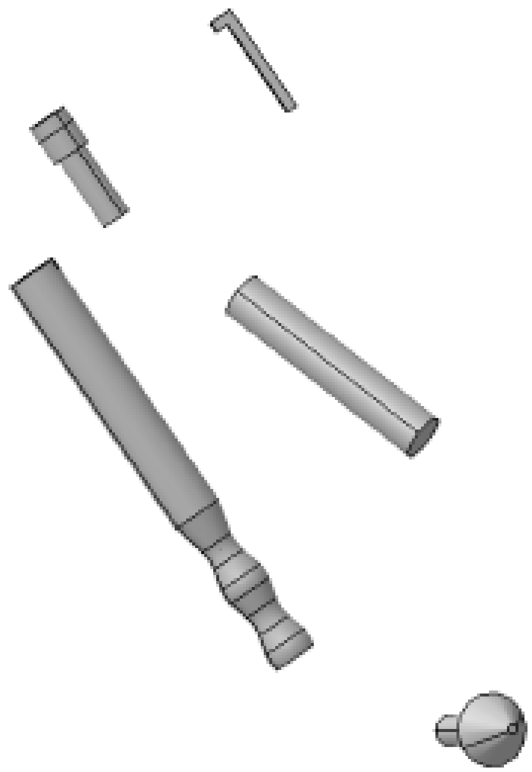
(b)



(c)



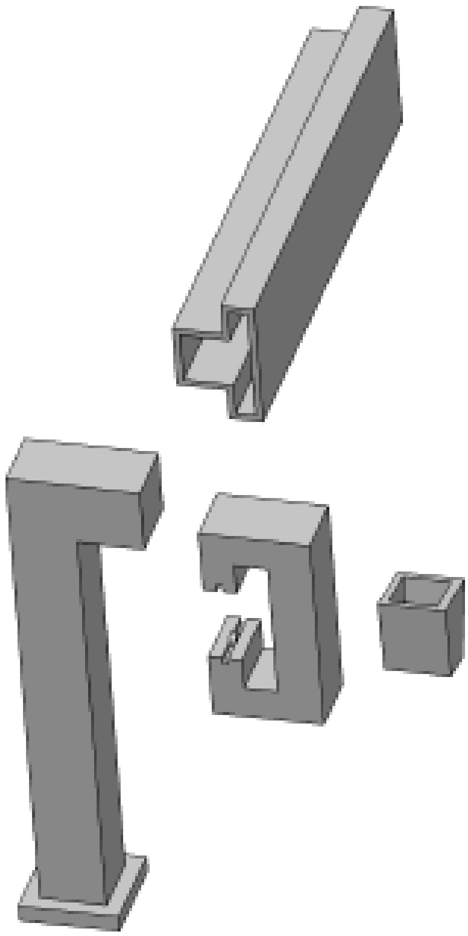
(d)



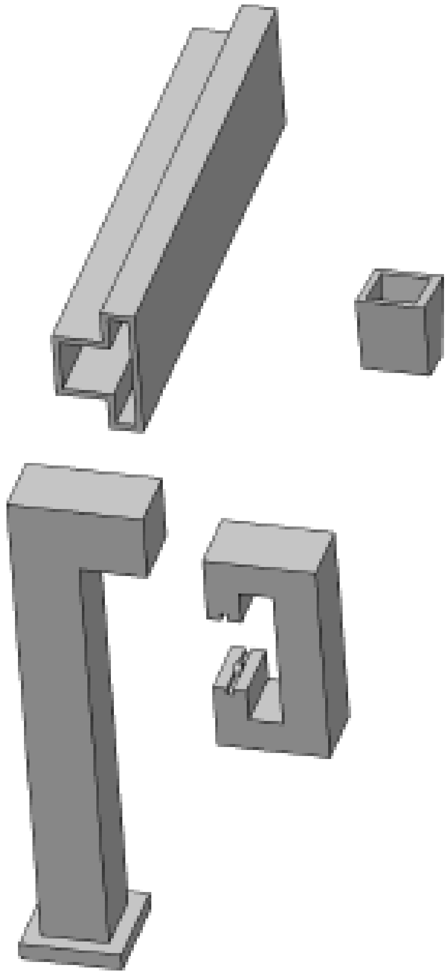
(e)

Figure 2. Assembly parts of (a) best mechanical pencil design alternative The second best (number 6 design alternative) (c) The third best (number 13 design alternative) (d) The fourth best (number 18 design alternative) (e) The fifth best (number 24 design alternative) design alternatives.

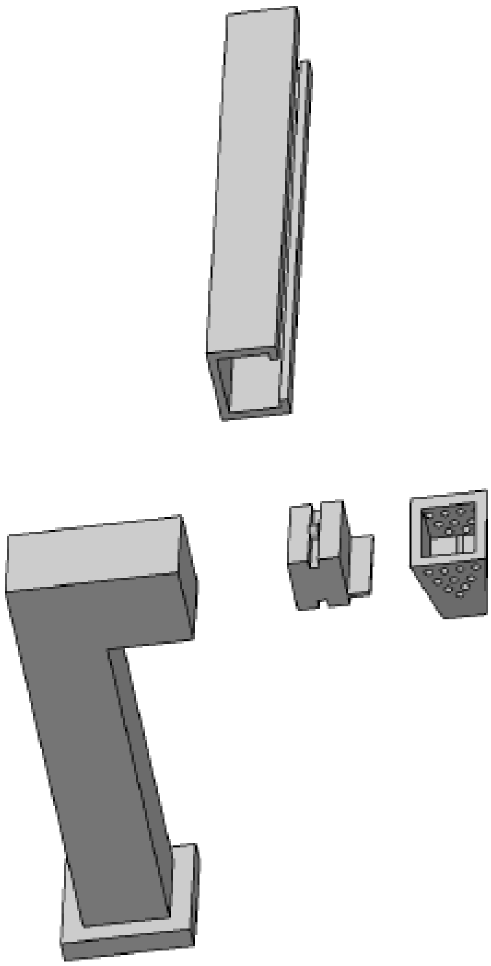
3. THE LARGE APPEARANCE of THE MANIPULATOR FRAME



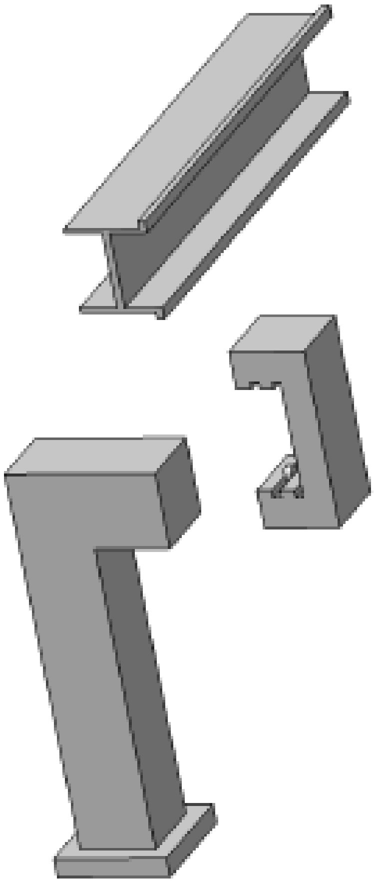
(a)



(b)



(c)



(d)

Figure 3. Assembly parts of (a) The best manipulator frame design alternative (b) The second best (number 25 design alternative) (c) The third best (number 4 design alternative) (d) The third best (number 33 design alternative) design alternatives