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# A coherent teaching program for a course of product design at master degree level

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## Article Information

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*K2 Teaching guide,*
*K3 Integration of several methods,*
*K4 Information mapping*
*K5 Book selection*

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## Abstract

Purpose:

*The paper discusses about the teaching program of the "Product Design and Development" course held at the University of Calabria (Italy) for the master degree in mechanical engineering. The course is placed at the second year (third semester) and is 6 ECTS.*

Method:

*In the course are employed most of the methods about engineering design that have been developed during the last half century. Collecting several methodologies born in different geographical area worldwide students are guided to elaborate a valid solution to a problem proposed by a firm operating in the manufacturing field.*

Result:

*A set of products designed by the students are presented, complete of all the aspects studied in the course*

Discussion & Conclusion:

*The scheduling of the course and the steps followed are reported. The difficulties encountered by students and the more critical topics that require more attention are underlined. A particular reflection is that does not exist a single text book able to support all the course and the major work in the years has been to select the right parts from all the books written about the topic of product design, engineering design and related methodologies.*

## 1 Introduction

After ten years of work it is possible to sum up the experience matured at the University of Calabria in the course of "Product Design and Development", to discuss the teaching approach and the road map rationale.

During the course of "Product Design and Development" the students have to design an industrial product. They have to generate many possible solutions and choose among them and continuously trade off for the definition of product component main characteristics. In the literature, many methods have been suggested to aid the design process and many of them can be profitably used for single phases determined by domain-specific views. Several road maps can be followed according to the personal attitudes of designers and the degree of stakeholder involvement.

The road map of the course involves the following ordered steps: A general introduction to "the nature of design", "the design ability" and "the design process", the Identification of Task, Market Analysis and Customer Needs, Product Functional Analysis by means of clustered graph and tree, Concept Generation (6-3-5 method and brainstorming) and Concept Selection (screening and scoring), Product Architecture, Customer Satisfaction (Kano model), Axiomatic Design, Quality Function Deployment (House of Quality), Design for Assembly-Manufacturing-Environment, Robust Design (Taguchi method), Detail Design.

The course is positioned at the second year of the master degree in Mechanical Engineering and it can be considered a course of synthesis, where put at disposal all knowledge acquired during the study.

## 2 The main difficulties

Students in engineering schools can find several courses in their curriculum covering the methodologies of embodiment or detail phases, because these derive from the classical analytical asset of engineering studies. Their major lack is concentrated in the whole treatment of design: the study of synthesis.

### 2.1 Functional analysis

During conceptual design the main difficulty is the extraction of a set of functional requirements from the customer needs that have been gathered by means of questionnaires or interviews in the initial phase of research for a new product or the revision of earlier versions. Generally students have no idea how this step can be taken. This is the first course in "product design" even if the course is scheduled almost at the end of the curriculum studiorum (in Italy this is the general organization of engineering studies). They speak and think of elements or parts they have realized and of which they have consciousness, but are not able to activate a functional reasoning.

The research for Functional Requirements starts instead from the translation of the component/element properties to their functional characteristics. The use of the couple “active verb + noun” to describe the element functionality is the most difficult moment during the course. Students of engineering courses, at the end for their regular studies, are generally able to analyze a wide range of situations and/or element behaviors on the basis of theories or application models. In the context of product development they lack a certain ability to talk and think about functionality. A general complexity emerges when they are invited to describe a functionality in terms of “verb + noun”. Even if in the past a certain number of codifications were tried and suggested for the actions that could be present in a device, the approach followed in this course is to use freely a variety of synonymous verbs with which a variety of situations can be precisely described. Also the nouns can be varied using synonyms and also the context could be specified by adding simple propositions.

Functional analysis is pursued decomposing the macro functionality, which characterizes the problem to be solved, in sub-functionalities, each of these able to evidence more precisely contexts and properties that might be present in the final solution. In this functional context the decomposition must be carried out refining the terminology used, trying to enhance property that otherwise could remain hidden or not explicitly stated. Since the linguistic terms that can be employed are really numerous, the decomposition can lead to quite different relations. If this generates bewilderment in students, accustomed to using a well-codified model and theory, it can allow them to solve a problem in an original way, trusting to the basic assumption that the decomposition is not unique.

### 2.2 Validation of solution

The Axiomatic Design method can give a valid support at the early stage of product design, by the application of the first Axiom. In this phase the designer is urged to individuate the right Design Parameters (DPs) that must be associated with the Functional Requirements (FRs) that have been identified in the previous step. Also for this analysis the designer should arrive at a square matrix as a necessary condition in order that a problem can be formally analysed. The study of the Design Matrix can guide the designer to discover hidden contradiction in the solution, or better, in the way how the FRs are performed by real components and are controlled by suitable DPs. The sufficient condition by which a problem can be validly controlled requires a lower triangular matrix. For the designer it is important to reach this state and the Design Matrix form gives most useful information on how to modify the solution. In fact, this crucial phase can require either a better search for new parameters or a radical revision of the product architecture and/or the search for a new formulation of the FRs, which, being expressed in the classical form of “active verb + noun”, can require major stress in the expression used. Until a lower triangular matrix (or ideally a diagonal matrix) is reached the designer must return to the previous domain (Functional Domain) and re-elaborate the solution.

A further phase can be taken into account when most of the problems are solved and the robust design phase should start. The emphasis is therefore centered on the way in which the solution performs with respect to the target defined at the beginning. In this phase the second Axiom can suggest where to investigate for a better solution.

The validity of the solution is verified by means of the Robust Design methodology. In particular the Taguchi method is introduced and employed for the analysis of a nucleus of relation among FRs and DPs identified in the design matrix. In it several groups of relations can be recognized and after the selection, in agreement with the tutor, of the most suitable one that can be simulated by means of some CAE system, the validation of the second axiom can start.

Even the relation between FRs and DPs shares the same tree structure, the simulation and the experimental design put in relation a macro functionality with the set of design parameters associated to it.

This kind of study has the task to familiarize students with the concept of right dimensioning and further of optimization. The right dimensioning is reached after a certain number of trials, trying to reduce the bias between the design range and the system range. The optimization is verified on the basis of the signal/noise ratio concept of the Taguchi method: the second axiom will be satisfied when the combination of Design Parameters guides towards the maximization of the ratio.

## 3 The course Road Map and the single steps

The course of Product Design and Development is scheduled for the second year of the Master in Mechanical Engineering at the University of Calabria. It is one of the four courses held in the autumn semester, lasting 14 weeks. The development of a project is intimately correlated to the discussion of the theory. The course requires 3 hours per week for lectures and 2 hours of workshop, with other 5 hours of self study, with a total amount of 6 credits. The delivery of the projects is scheduled 1 month after the end of the semester. Students are subdivided into groups of 3-4 people in order to simulate a designer team and all projects are discussed in a one-day-seminar, when each student presents a part of the project. A second part of the exam requires one individual session, to verify the degree of knowledge of all the subjects presented during the semester.

The theme for the semester project, last autumn 2012, was required by a Firm operating in Calabria, which “designs, manufactures and trades technologies and systems for aluminium shutters, windows and doors, and designs, manufactures and trades mechanisms for shutters and accessories for shutters, windows and doors.” (http://www.teknalsystem.it).

The problems proposed were to design “a movable slats shutters easy to be inserted” and a device “to fix the shutter at wall while open”. A set of customer needs was filtered by the Firm stakeholders who imposed some characteristics to the devices to be designed. Each group of students had to decide which problem to solve.

After a general knowledge of the mechanisms, the students were introduced to the product functional analysis and they become familiar with these functionalities. They started to draw the first graphs and trees and to reason about the way the team tried to solve the problem. After a certain time and a certain level of acquired knowledge, they generated a set of solutions for each of the declared functionalities, by means of the 6-3-5 method, in one creative session of three hours. In a general discussion about the solutions found, each group was able to assemble a certain number of solutions, with the help of morphological matrices in which all the elements of interest were classified. Generally, this first generative session was followed by other sessions self organized by each group, every time new and intriguing solutions emerged during discussion.

After the selection phase, the most promising idea was transferred into the Design Matrix and the analytical work to verify the first axiom of Axiomatic Design was done. A certain number of revisions are required in this step, because the right parameters cannot be identified at first sight. This being the crucial phase, which can license the validity of a solution, the team work is reviewed systematically by the course tutor.

The filling of all the rooms of the House of Quality gives to the students a wider overview of their work, and stimulates them to consider the actual difficulty in designing. They must realize that their work is only a part of a more complex work. The relation matrix of QFD has a rectangular form since the number of rows, in which the Customer Needs (CNs) are reported, can be different from the number of columns, in which the main characteristics of the solution found are reported. The main characteristics, so generally named in the literature, in this approach coincide with the Design Parameters, which emerge after the conjoint work in the Functional Domain and the Axiomatic Domain.

Customer satisfaction, with the employment of the Kano model, at this point of development, gives other information about the hypothetical success of the solution found.

Methodologically, the design continues with the application of well-stated strategies: Design for Manufacturing and Assembly suggest how the best solution found can be profitably implemented in the Firm that required the design, changing forms and materials to the components that could be built in house. Design for Environment considerations can allow students to realize the importance of planet resources and their better use. Just to fill a MECO matrix and perform a qualitative assessment by means of the ECODESIGN Pilot is sufficient introduction to the subject.

Robust Design, performed by the DOE and Taguchi Method and applied to some components, allowing students to familiarize themselves with optimization. In conjunction with simulations by means of CAE software they have the possibility of enhancing their sensitivity to define the parameter range.

In the following (see Appendix) two of the semester projects for “a device to fix the shutter at wall while open”, discussed during the final seminar are reproduced. They are written in Italian, even if this is not a problem to understand the actual value of the work.

## 4 A selection of subjects from text books

A certain difficulty in this kind of course consists in supporting students with sufficient material for all parts. This year was given students the information where they would have found the best notes.

From the book by Cross [1] were selected the first 4 chapters, as a general introduction to the themes of “the nature of design”, “design ability” and “the design process” and “new design procedures”.

From the book by Palh and Beitz [2] were selected the chapters 3 “process planning and design” and 5 “product planning and clarifying the task”.

Again from Cross the chapter 6 “establishing function” and from the book by Otto and Wood [3] the chapter 5 “establishing product function”.

From the book by Ulrich and Eppinger [4] were selected the chapters 7 “concept generation” and 8 “concept selection”.

From the book by Suh [5] were selected the chapters 1 and 3.

Quality Function Deployment was selected from Cross, chapter 8, and Otto and Wood, chapter 7.

Design for Manufacturing and Assembly were selected form Otto and Wood chapter 14.

About robust design was selected the chapter 12 from Erto [6] and the chapters 4, 5 and 6 from Roy [7].

For the subjects of design for environment and Kano model a set of materials were distributed to students.

The coordination and concatenation of the subjects and mainly the project data mapping among the several methods employed along the whole process are reported in Rizzuti [8].

## 5 Conclusion

The paper has reported the experience done in a decade of teaching Product Design and Development. The major contribution of the paper is to underline the extreme difficulty in recommending and/or adopting a text book about this subject. Every book has a proper point of view that highlight some aspects instead then others. And for this reason the best selection of materials required a lot of time. In a certain sense, also this selection of materials presumes a point of view, and for this reason the author has decided to present the paper, hoping to stimulate the discussion.

## Acknowledgement

I would be glad to thank all the students who attended the course this year, because with their work they allowed to verify the coherence of the road map proposed to them. Many thanks to PhD Eng Francesco Giampà, technician of the Firm, for the continuous discussion with students.

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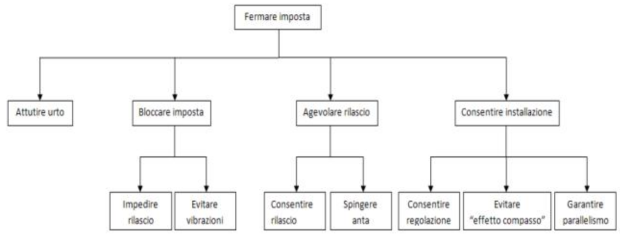
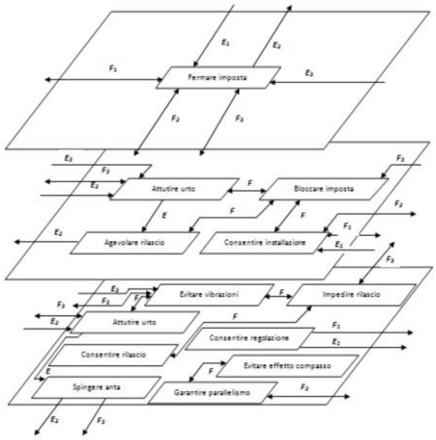
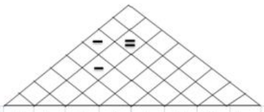
# Appendix

Team Project: *Daniele Galati, Alessandro Imineo, Fernando Bernaudo, Salvatore Maiorano.*

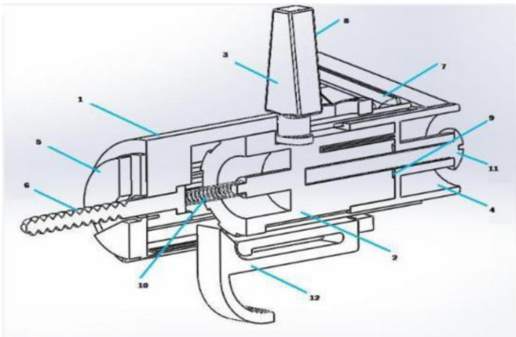


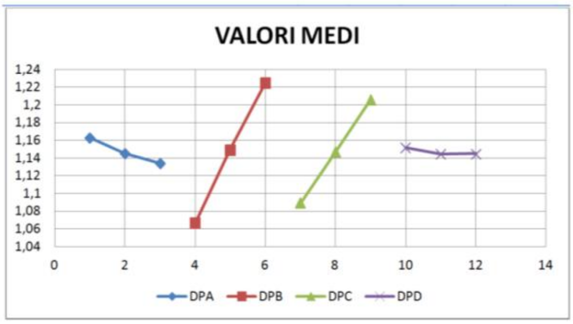



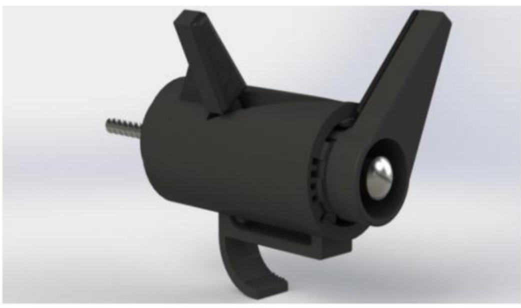
| RELATIVE IMPORTANCE / ENGINEERING CHARACTERISTICS | | ↑ ABBASSAMENTO ELEMENTO DI BLOCCO | ↑ COMPRESSIONE MOLLA | ↑ DIAMETRO BASE CIRCOLARE | ↑ RANGE DISTANZA SUPPORTI | ↑ SPESSORE GUAINA POLIMERICA | ↑ ALTEZZA RESIDUA DI BLOCCO | ↓ COSTANTE ELASTICA MOLLA | ↑ SPESSORE DISTANZIALI | FERMAIMPOSTE PSP | Block, Tecknal System | Grillo , Esinplast | Speedy, Fibi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRATICITA' DI UTILIZZO | 30 | 9 | 9 | | | | | 3 | | 4 | 2 | 3 | 3 |
| ESTETICA | 21,7 | | | 6 | | 3 | | | 3 | 3 | 4 | 4 | 2 |
| ROBUSTEZZA | 21,7 | 6 | | 6 | 6 | 6 | 9 | 3 | | 5 | 5 | 2 | 3 |
| FACILITA' DI MONTAGGIO | 13,3 | | 6 | 3 | 3 | | | | 6 | 2 | 3 | 4 | 5 |
| POSSIBILITA' DI REGOLAZIONE | 13,3 | | | | 9 | | | | | 3 | 4 | 2 | 4 |
| IMPORTANZA TECNICA ASSOLUTA | | 400 | 349,98 | 300,03 | 289,98 | 195,03 | 195,03 | 155,01 | 144,99 | **17** | **18** | **15** | **17** |
| IMPORTANZA TECNICA PERCENTUALE | | 19,7 | 17,24 | 14,779 | 14,284 | 9,6071 | 9,6071 | 7,6357 | 7,1421 | **360.01** | **348.34** | **300** | **318.32** |
| UNITA' DI MISURA | | mm | mm | mm | mm | mm | mm | N/mm | mm | | | | |
| TARGET | | 3 a 5 | 15 a 20 | 38 a 50 | 22 | 3 a 6 | 0 a 3 | 0,67 a 1 | 5 a 15 | | | | |
| Block | | n.a. | 13,8 | 41,5 | 55 | 22 | n.a. | 0,15 | 10 | | | | |
| Grillo | | n.a. | 9 | 39 | 16 | n.d. | n.a. | n.d. | 7,5 | | | | |
| Speedy | | n.a. | 5 | 35 | 60 | n.a. | n.a. | n.d. | 7,5 | | | | |

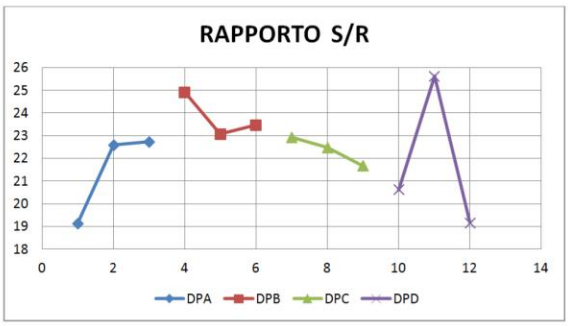
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***EVITARE URTO*** | MOLLA LINEARE | MOLLA A TORSIONE | SMORZATORE VISCOSO | GOMMA | FRAZIONAMENTO AMMORTIZZATORI IN GOMMA | MOLLA A LAMINA | |
| ***IMPEDIRE RILASCIO*** | CORPO RIGIDO (VEDI GRILLO) | VENTOSA | CALAMITA | MOLLA A LAMINA | BLOCCO INFERIORE | | |
| ***EVITARE VIBRAZIONI*** | MOLLA – SMORZATORE | ELEMENTO FLESSIBILE POLIMERICO | CUSCINETTI POLIMERICI | VENTOSA | APPENDICI IN SERIE MOLLE A LAMINA | DOPPIA MOLLA | |
| ***CONSENTIRE RILASCIO*** | ELEMENTO ANTERIORE CON CERNIERA | ELEMENTO ANTERIORE A TRASLAZIONE VERTICALE CON MOLLA | ELEMENTO ANTERIORE A TRASLAZIONE VERTICALE SENZA MOLLA | TORSIONE ELEMENTO ANTERIORE | ROTAZIONE RIGIDA (VEDI GRILLO) | ELEMENTO ANTERIORE CHE RUOTA (VEDI BLOCK) | TORSIONE SIMULTANEA ANTERIORE E POSTERIORE |
| ***SPINGERE ANTA*** | MOLLA LINEARE | MOLLA A LAMINA | MOLLA A TORSIONE CORPO CENTRALE | CALAMITA | ELEMENTO CON ELEVATO RITORNO ELASTICO | SISTEMA DI LEVERAGGIO | TORSIONE ELEMENTO ANTERIORE |
| ***CONSENTIRE REGOLAZIONE*** | VITE DI MANOVRA | ELEMENTO ANTERIORE POSIZIONABILE A PRESSIONE | ELEMENTO POSTERIORE POSIZIONABILE A PRESSIONE | ELEMENTO ANTERIORE FILETTATO | ELEMENTO POSTERIORE FILETTATO | VITE ELEMENTO ANTERIORE | TRASLAZIONE CORPO CENTRALE |
| ***EVITARE EFFETTO COMPASSO*** | BASE CIRCOLARE | COLLA | CHIODI | VENTOSA | CORPO A MURO FISSO (ROTAZIONE DEL SOLO CORPO CENTRALE) | SOTTO VUOTO | |
| ***GARANTIRE PARALLELISMO*** | DISTANZIALI (VEDI BLOCK) | VITE - MADREVITE | ELEMENTO TELESCOPICO | | | | |



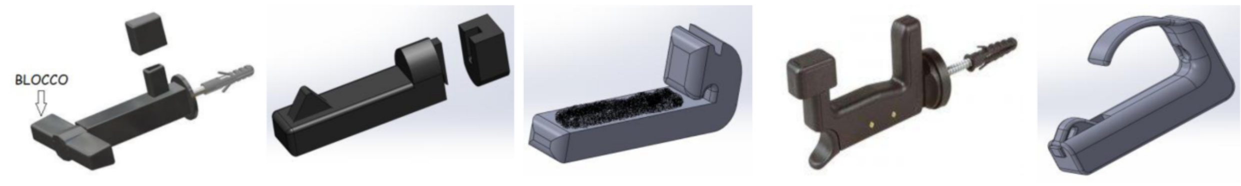
1. CORPO CENTRALE
2. ELEMENTO POSTERIORE
3. APPENDICE POSTERIORE
4. ELEMENTO ANTERIORE
5. DISTANZIALE
6. VITE A TESTA QUADRA
7. GOMMA ELEMENTO ANTERIORE
8. GOMMA ELEMENTO POSTERIORE
9. ANELLO SEEGER
10. MOLLA
11. VITE A CALOTTA
12. SNAP (ELEMENTO DI SBLOCCO)





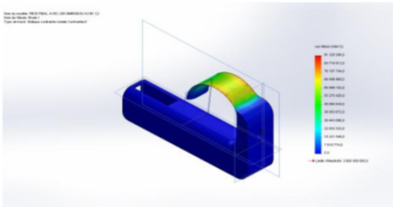
Team Project: *Hamza Riahi, Haithem Ferjani, QiuXiang Zhou.*

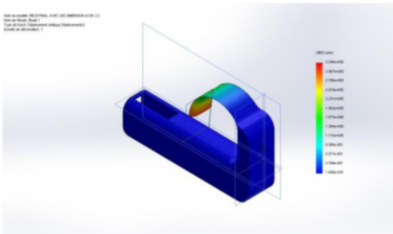


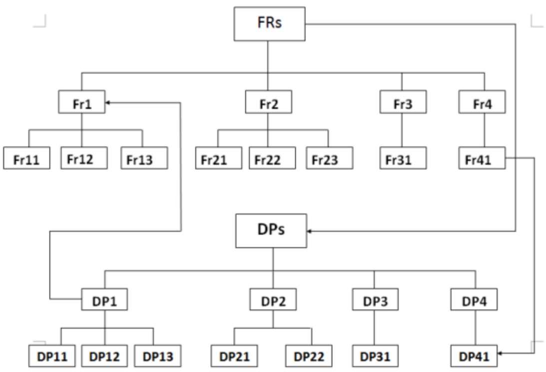

| SCREENING | | | | | |
|---|---|---|---|---|---|
| Criteri di selezione | Soluzione 1 | Soluzione 2 | Soluzione 3 | Soluzione 4 | Soluzione 5 |
| Estetica | - | - | + | - | + |
| Praticità di utilizzo | - | - | + | + | 0 |
| Facilità di montaggio | + | 0 | - | + | + |
| Possibilità di montaggio | + | + | - | + | + |
| Robustezza | 0 | 0 | - | - | 0 |
| Peso | + | + | + | + | + |
| Riciclabile | 0 | 0 | 0 | - | 0 |
| Durabilità | + | + | - | - | 0 |
| Total sum + | 4 | 3 | 3 | 4 | 4 |
| Total sum 0 | 2 | 3 | 1 | 0 | 4 |
| Total sum - | 2 | 2 | 4 | 4 | 0 |
| Score | 2 | 1 | -1 | 0 | 4 |
| Rank | 2 | 3 | 5 | 4 | 1 |

| Matrice di Importanza Relativa | | | | | | | |
|---|---|---|---|---|---|---|---|
| CN | Estetica | Praticità di Utilizzo | Facilità di montaggio | Possibilità di regolazione | Robustezza | ΣVi | ΣPi (peso) |
| Estetica | - | 1 | 1 | 1 | 1 | 4 | 0.067 |
| Praticità di utilizzo | 5 | - | 4 | 3 | 3 | 15 | 0.25 |
| Facilità di Montaggio | 5 | 2 | - | 2 | 3 | 12 | 0.20 |
| Possibilità di regolazione | 5 | 3 | 4 | - | 3 | 15 | 0.25 |
| Robustezza | 5 | 3 | 3 | 3 | - | 14 | 0.233 |
| | | | | | | | |
| 1 2 3 4 5 | | | | | | | |
| meno importante più importante | | | | | | | |

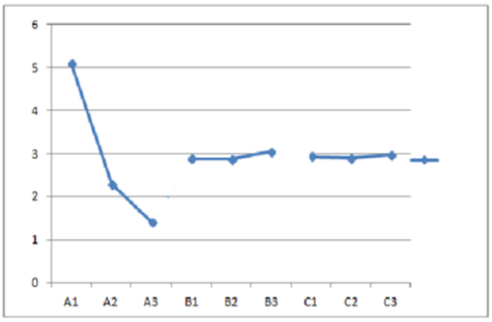
| SCORING | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Soluzione 1 | | Soluzione 2 | | Soluzione 5 | |
| Criteri di Selezione | Peso | Rating | Weight Score | Rating | Weight Score | Rating | Weight Score |
| Estetica | 0.0469 | 2 | 0.0938 | 2 | 0.0938 | 4 | 0.1876 |
| Praticità di Utilizzo | 0.175 | 2 | 0.35 | 2 | 0.35 | 3 | 0.525 |
| Facilità di montaggio | 0.14 | 4 | 0.56 | 3 | 0.42 | 4 | 0.56 |
| Possibilità di regolazione | 0.175 | 2 | 0.35 | 4 | 0.7 | 2 | 0.35 |
| Robustezza | 0.175 | 3 | 0.525 | 3 | 0.525 | 3 | 0.525 |
| costo(0.3) | | | 0.3 | | 0.3 | | 0.3 |
| Total score | | | 2,1788 | | 2,388 | | 2,4476 |
| Contine? | | NO | | NO | | DEVELOP | |
| | | | | | | | |
| | | | | | | | |
| Relative Performance Rating | | | | | | | |
| much worse than reference | | 1 | | | | | |
| worse than reference | | 2 | | | | | |
| samne as reference | | 3 | | | | | |
| better than reference | | 4 | | | | | |
| much better than reference | | 5 | | | | | |








**VALORI MEDI**

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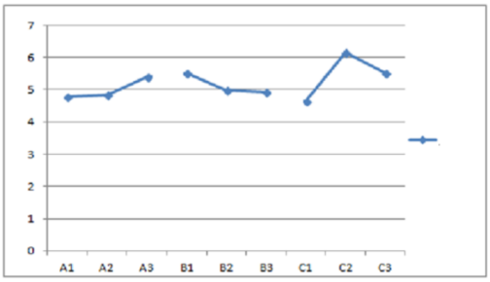


| | | DP1 | | | DP2 | | | DP3 | | | DP4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DP11 | DP12 | DP13 | DP21 | DP22 | DP23 | DP31 | DP32 | DP33 | DP41 | DP42 | DP43 |
| | FR11 | X | | | | | | | | | | | |
| FR1 | FR12 | | X | | | | | | | | | | |
| | FR13 | | | X | | | | | | | | | |
| | FR21 | | | | X | | | | | | | | |
| FR2 | FR22 | | | | | X | | | | | | | |
| | FR23 | | | | | | X | | | | | | |
| | FR31 | | | | | | | X | | | | | |
| FR3 | FR32 | | | | | | | | X | | | | |
| | FR33 | | | | | | | | | X | | | |
| | FR41 | | | | | | | | | | X | | |
| FR4 | FR42 | | | | | | | | | | | X | |
| | FR43 | | | | | | | | | | | | X |