Design For Six Sigma Applied to the Design of an Innovative Food Processor

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Abstract

Nowadays technology is extensively used as aid for cooking activities and humans are relying on it for a wide range of tasks in their everyday life, making the cooking activity more effective, less time consuming and even accessible to less skilled people. The present work is a case study on the application of the Design for Six Sigma (DFSS) methodology that here is exploited for the realization of the so-called "food processor". This device requires only electricity, it is able to cook, mix, chop up and steam, allowing the user to obtain tasty and well-controlled dishes through simplified procedures. The method used looks at what is already available on the market enabling to design an innovative product while fulfilling customer requirements. QFD analysis and Benchmarking analysis were used as a support for the method. The result of the research is the design of an innovative food processor, where the design procedure has been guided by DFSS methodology and has been implemented through Creo Parametric software.

Keywords
Quality Function Deployment (QFD), Benchmarking Analysis, Design for Six Sigma (DFSS), Food Processor.

1. Introduction

The Six Sigma methodology was born in company realities as a support tool for improving production processes.
The goal of this approach is to improve customer satisfaction starting from the customer's requests. In the first analysis it is necessary to identify the Critical to Quality (CTQ) characteristics, that is, the characteristics of a product or process that must comply with (specific) criteria in order not to generate customer dissatisfaction. The more the CTQ characteristics respect the specifications defined by the customer's requests, the more the production process is performing.

The Six Sigma approach stems from an evidence: no process is able to generate two units of finished product that are absolutely identical to each other or guarantee a perfectly constant level of service over time. Thus, the need arises to define specification limits that can be judged as compliant also for specimens whose characteristics differ (to a reasonably limited extent) from the nominal specifications.
Design for Six Sigma consists of a design method for the development of new products that aims to better respect the customer's requests and expectations. This research is based on products that already exist: the aim is to be able to eliminate defects and contradictions found in the products on the market, so as to be able to obtain a more satisfying and innovative new product.
There are different approaches to applying the method:
- DMADV; Define, Measure, Analyze, Design and Verify.

- CDDOV; Concept, Define, Design, Optimization and Verification phases.
- IDOV; Concept, Design, Optimize, Verify.
- IDDOV; Identify, Define, Develop, Optimize, Verify.
- RADIOV; Requirements, Architecture, Design, Integration, Optimization, Verification.

Although each approach follows its own guideline, it is possible to identify some common phases. The basic activities that are performed in a Design for Six Sigma approach are the following: investigation of customer requests and needs, analysis and classification of these requests, transformation of customer requests into engineering information, development of a design, verification of performance and implementation of processes in line with the objective to be achieved.

The DMADV approach is the most used in the field of Design for Six Sigma.

As previously mentioned, this approach consists of 5 distinct phases: Define, Measure, Analyze, Design and Validate. Each phase has its own goal, at the end of the last phase a design will be achieved in line with the Design for Six Sigma methodology.

- *Define*
  During the first phase, information is collected on what the customer's requests and needs are. Specifically, it is important to note what the problems are that the customer encounters by approaching a specific product already on the market. These problems will then be the starting point for the development of the new product.
- *Measure*
  In this phase we work through the QFD analysis to translate the customer's needs into engineering information. In this way it is possible to obtain which are the characteristics linked to the design which influence whether or not to respect the customer's requests.
- *Analyze*
  The key characteristics obtained in the second phase are exploited to conceive the design of the new product. For this purpose, a benchmarking analysis is carried out, which allows to study similar designs of competitive models with the product in question.
- *Design*
  Depending on what has been obtained from the analysis phase, the new product is designed with appropriate software. In this phase it is necessary to take into consideration all the information obtained from the previous points and try to respect them at best.
- *Verify*
  In the latter phase, it is stated with certainty that the finished product confirms the expected results. Prototypes can be produced for testing to ensure that the product is in line with the required characteristics.

The paper continues with the application of DFSS method to the design of an innovative food processor.

2. Design

To start a project it is necessary first of all to carry out a first phase of data collection and selection which goes by the name of "task clarification phase". This phase allows you to define the problem as completely and clearly as possible, so that the corrections in the subsequent phases are limited.

A first revision of the project includes questions of this type:

important tools able to carry out this conversion is the interrelation matrix and the matrix of relative importance, whose explanation will be proposed later.

Who? (Who uses the food processor?)
The product is used both in the family and in working contexts such as B & Bs and restaurants, there is a varied type of user.
Resulting requirements: safety, efficiency, ease of use, multifunctionality.

What? (What is its function?)
Its function is to prepare numerous types of dishes in short times and with controlled recipes.
Resulting requirements: efficiency, compactness, eco-compatibility, multifunctionality.

Where? (Where is it used?)
The product is used in the kitchen.
Resulting requirements: aesthetically pleasing, limited size, resistance to heat and humidity, ease of cleaning.

When? (When is it used? And how many times?)
The product is used in the hours before meals. Normally it can be used up to 2 times a day.
Resulting requirements: mechanical resistance, easy to clean, maintenance.

Why? (Why is it used?)
The product is used because it always guarantees excellent results, the possibility of error is extremely limited. Furthermore, one is guided during the use of the product itself and for this reason high culinary skills are not required.
Resulting requirements: ease of use, devices that facilitate their use.

How? (How is it used?)
The use of the product requires the collaboration of machine and man, the physical presence of man is essential.
Resulting requirements: safety, ease of use, easy handling.

3. Measure

The requirements obtained now need to be sorted and weighed according to their role within the development of the project. For this purpose, the QFD proposes the use of two different matrices: the interrelation matrix and the matrix of relative importance. As already mentioned, the two matrices are used to convert qualitative data obtained from the six-questions method into quantitative data that can be processed by classical data processing methods.

The *Interrelation matrix* is applied to the current case. The requirements are arranged on rows and columns. Subsequently the relationships that link the requirements to each other are established by means of a score. The higher the degree of dependence between two requirements, the higher the associated score.

Requirements	1	2	3	4	5	6	7	8	9	10	11	12	13	TOT
1. Safety		9	9	9	3	1	3	9	0	0	0	9	9	61
2. Efficiency	9		0	9	1	1	9	3	9	0	1	3	9	54
3. Mechanical resistance	9	9		9	3	3	0	0	1	3	0	3	9	49
4. Maintenance	9	3	9		0	3	0	3	3	0	0	3	3	36
5. Ease of use	3	3	0	0		0	9	0	3	1	0	0	9	28
6. Compactness	3	3	3	0	3		0	0	3	3	9	0	9	36
7. Easy handling	1	9	0	0	9	3		0	1	3	3	0	0	29
8. Eco-compatibility	9	1	9	9	0	0	0		1	0	0	3	0	32
9. Multifunctionality	0	9	0	0	9	0	0	0		1	9	0	9	37
10. Aesthetically pleasing	0	0	0	0	0	1	3	0	1		3	0	0	8
11. Limited size	0	0	0	0	1	9	0	0	1	9		0	1	21
12. Resistance to heat and humidity	9	9	9	0	9	1	0	3	0	0	0		0	40
13. Ease of cleaning	3	3	0	3	9	3	1	0	3	0	1	0		26
TOTAL	55	58	39	39	47	25	25	18	26	20	26	21	58	

Legend
No addiction: 0
Weak addiction: 1 point
Medium addiction: 3 points
Strong addiction: 9 points

The 13 requirements obtained in the define phase are compared in the interrelation matrix.
The most independent requirements were selected taking 80% of the maximum manifested value as the lower limit, in this case $80/100 \cdot 58 = 46.4$ points.
For more independent requirements, the minimum value is $80/100 \cdot 61 = 48.4$ points.
For the requirements that had maximum sum both in row and in column, the greater sum was selected between the dependency score and the independence score (e.g. safety).
It follows that the most independent requirements are: ***efficiency, ease of cleaning and simplicity of use.***

Then the study proceeds with the use of the *Relative importance matrix*, which highlights which requirements are the most important.

Requirements	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Safety	1	1	1	1	0	0	0	1	1	0	0	1	0
2. Efficiency	1	1	1	1	1	0	0	1	1	0	0	1	0
3. Mechanical resistance	1	1	1	1	0	0	0	1	1	0	0	1	0
4. Maintenance	1	1	1	1	1	1	1	1	2	0	1	1	1
5. Ease of use	2	1	2	1	1	0	1	0	1	0	0	1	1
6. Compactness	2	2	2	1	2	1	1	0	1	1	1	0	1
7. Easy handling	2	2	2	1	1	1	1	0	1	1	1	0	1
8. Eco-compatibility	1	1	1	1	2	2	2	1	1	0	0	1	0
9. Multifunctionality	1	1	1	0	1	1	1	1	1	0	0	0	0
10. Aesthetically pleasing	2	2	2	2	2	1	1	2	2	1	1	0	1
11. Limited size	2	2	2	1	2	1	1	2	2	1	1	0	1
12. Resistance to heat and humidity	1	1	1	1	1	2	2	1	2	2	2	1	0
13. Ease of cleaning	2	2	2	1	1	1	1	2	2	1	1	2	1
TOTAL	19	18	19	13	15	11	12	13	18	7	8	9	7

Legend
Row is more important than column: 0
Row and column have the same importance: 1 point
Row is less important than column: 2 points

To evaluate the most important characteristics, a minimum value lower than 80% of the maximum manifested value was taken. In this case, the minimum value required to be among the most important characteristics is $80/100 \cdot 19 = 15.2$ points.
It follows that the most important characteristics are: ***safety, efficiency, mechanical resistance and multifunctionality.***

4. Analyze

The key requirements obtained in the second phase are exploited to conceive the design of the new product. For this purpose, the *Benchmarking analysis* is proposed.
The *Benchmarking Analysis* is a comparison operation between competing companies. Through this type of analysis it is possible to identify the strengths and weaknesses of each company (and its related product). In a business context, *Benchmarking analysis* is a continuous process that places the company in comparison with the best leaders in the sector with the ultimate goal of achieving the best performance.
Operationally, this method consists of a first identification of the subject of comparison: it could be a product, as a process management methodology, time and cost indicators. Then follows the definition of the companies to be compared: a consistent number of companies allows to obtain more reliable results.

The *Benchmarking analysis* was applied to compare the technical characteristics of eight food processors currently on the market.
The following models are examined:

- Thermomix TM5, Vorwerk.
- Klarstein Food Circuis, Klarstein.
- Moulinex Cuisine Companion, Moulinex.

- Imetec Cukò, Imetec.
- Kenwood kCook, Kenwood.
- Baby Meal Chicco De'Longhi & Me, De'Longhi.
- KitchenAid Cook Processor, Kitchenaid.
- Hotpoint MC 057C AX0, Hotpoint.

The technical comparison characteristics collected are:
- Engine power.
- Heating power.
- Touchscreen display.
- Maximum temperature.
- Ability.
- Height.
- Width.
- Depth.
- Weight.
- Maximum time that can be set.
- Price.
- Built-in scale.

Once all the data has been collected, the "Optimal characteristics" column is constructed: this column shows the best values shown for each characteristic accompanied by ">" or "<" if innovation requires that this characteristic be further strengthened or weakened.
For each row the characteristic representing the best value (TOP) is colored in green, in red for the worst value (FLOP). For each product, the TOP number and the FLOP number are counted, shown in the appropriate box below the matrix. The operation is then carried out:

$$\Delta = \text{ n ° TOP characteristics} - \text{n ° FLOP characteristics}$$

The Δ value is an index that expresses innovation: the higher Δ the higher the gap between the TOP characteristics that bring innovation compared to the FLOP ones.
From the *Benchmarking analysis,* the maximum Δ value currently on the market is obtained, the goal will then be to reach or better exceed this maximum value to qualify your product as the most innovative.

	Bimby TM5 	Klarstein Food Circus 	Moulinex Cuisine Companion 	Imetec Cukò 	Kenwood kCook 	Baby Meal Chicco De'Longhi & Me 	KitchenAid Cook Processor 	Hotpoint MC 057C AX0 	Optimal characteristics
1. Engine power	500 W	500 W	550 W	n.d	500 W	150 W	450 W	70 W	>550
2. Heating power	1000 W	1100 W	1000 W	570 W	800 W	800 W	1050 W	500 W	>1100
3. Touchscreen display	SI	SI	SI	SI	SI	NO	NO	SI	SI
4. Maximum temperature	120 °C	100 °C	130 °C	100 °C	180 °C	100 °C	140 °C	100 °C	> 180 °C
5. Volume	2,2 litres	2 litres	4,5 litres	1,2 litres	2,6 litres	1,5 litres	4,5 litres	1,5 litres	> 4,5 litres
6. Lenght	34,1 cm	38 cm	35 cm	34 cm	29 cm	25 cm	41 cm	33 cm	< 25 cm
7. Width	32,6 cm	25 cm	32 cm	32,5 cm	33,5 cm	24,5 cm	46 cm	22 cm	< 22 cm
8. Depth	32,6 cm	24 cm	31 cm	28 cm	26 cm	35 cm	34 cm	30 cm	< 24 cm
9. Weight	7,95 kg	8 kg	7 kg	5 kg	7,5 kg	6 kg	10 kg	4 kg	< 4 kg
10. Maximum time that can be set	99 mins	60 mins	120 mins	60 mins	60 mins	30 mins	90 mins	60 mins	> 120 mins
11. Price	1.299 €	259,99 €	699,99 €	199,99 €	599 €	190 €	1.029 €	499 €	< 190 €
12. Built-in scale	YES	NO	NO	NO	NO	NO	NO	NO	YES

TOP	2	3	4	1	2	2	1	3
FLOP	1	1	1	3	1	5	5	4
Δ	1	2	3	-2	1	-3	-4	-1

From the analysis conducted it follows that for the new product it should be:

$$\Delta_{new\ product} \geq 3$$

It was chosen to put:

$$\Delta_{new\ product} = 3 + 1 = 4$$

The number of characteristics on which to focus the research is thus known, the next step is to identify them qualitatively.
In this regard, an analysis is carried out on the technical characteristics observed: a matrix of importance regarding the technical characteristics is constructed, in such a way as to establish which features to keep and which to exclude for design purposes.

Characteristics	1	2	3	4	5	6	7	8	9	10	11	12
1. Engine power [W]	1	1	0	1	1	0	0	0	0	0	0	1
2. Heating power	1	1	0	1	1	0	0	0	0	0	0	1
3. Touchscreen display	2	2	1	2	2	0	0	0	2	0	0	2
4. Maximum temperature	1	1	0	1	1	0	0	0	0	0	0	1
5. Volume	1	1	0	1	1	0	0	0	0	0	0	1
6. Lenght	2	2	2	2	2	1	1	1	2	2	2	2
7. Width	2	2	2	2	2	1	1	1	2	2	2	2
8. Depth	2	2	2	2	2	1	1	1	2	2	2	2
12. Built-in scale	2	2	0	2	2	0	0	0	1	0	0	2
9. Weight	2	2	2	2	2	0	0	0	2	1	2	2
10. Maximum time that can be set	2	2	2	2	2	0	0	0	2	0	1	2
11. Price	1	1	0	1	1	0	0	0	0	0	0	1
TOTAL	19	19	11	19	19	3	3	3	13	7	9	19

Legend
Row is more important than column: 0
Row and column have the same importance: 1 point
Row is less important than column: 2 points

The most important characteristics are, on an equal footing, the engine power, the heating power, the maximum temperature, the volume and the price.
It is important to evaluate how much the technical characteristics influence the fulfillment of the requirements. For this purpose, an interrelation matrix is constructed in which the degree of satisfaction of each requirement is expressed according to a specific technical characteristic.

Technical features→ Requirements↓	Engine power motore	Heating power	Maximum temperature	Volume	Price
Safety	9	9	9	0	3
Efficiency	9	9	9	0	3
Multifunctionality	9	3	3	9	1
Mechanical resistance	9	9	9	0	1
Ease of use	1	3	3	3	0
Ease of cleaning	0	0	0	0	0
TOTAL	37	33	33	12	8

How much the technical characteristics influence the fulfillment of the requirements: 0, 1, 3, 9 points

The technical characteristics identified as most important can be ordered according to the degree of satisfaction of the requirements:

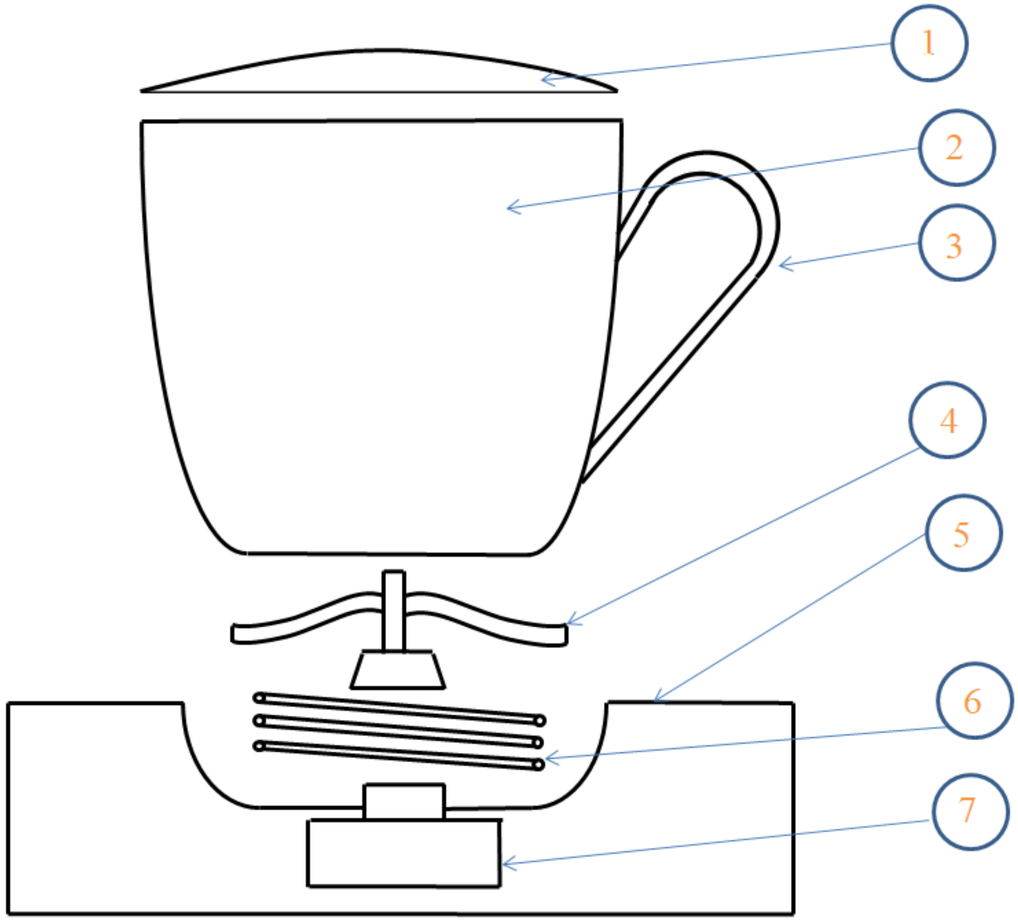
1. Motor power
2. Heating power
3. Maximum temperature
4. Capacity
5. Price

The last position occupied by the price is justified by the fact that the customer, being a product for the preparation of food, wants to buy a safe and quality product at the expense of a price that is possibly higher than expected. Thus the price occupying the last position is excluded from the set of features on which to focus the design.

In conclusion, the technical characteristics to focus on are: engine power, heating power, maximum temperature and capacity.
The customer's requirements to be met by improving the characteristics of the product are: efficiency, multifunctionality, ease of cleaning, safety, mechanical resistance and ease of use.

6. Design

The design phase requires knowledge and understanding of the architecture of the product that you intend to design. In the case in question, the main components of a food processor were identified by analyzing the structure of the eight robots that appeared in the *Benchmarking analysis phase* and thanks to the reading of some patents reported in the bibliography.
From this first analysis it is possible to structure a first and simplified product architecture.



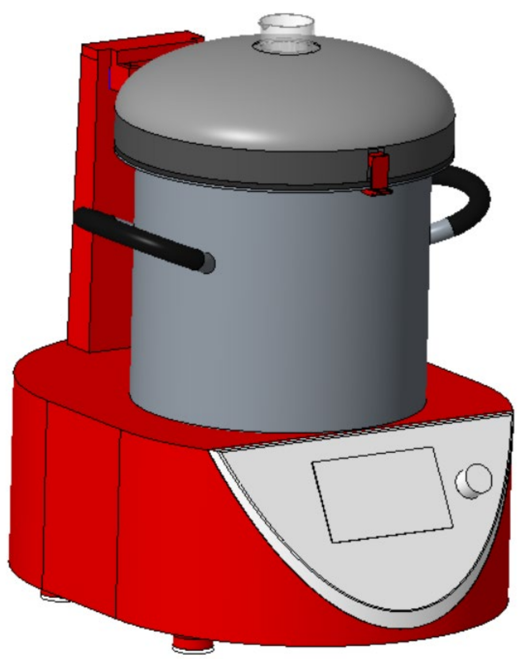
Following are the components that appear in the final design that is carried out with the Creo Parametric 3.0 program:

n°	Component	Function
1	Cover	Isolate the indoor environment to the pan during cooking.
2	Pot	Contain the dishes during the use of the food processor.
3	Handle	Allow the user to handle the container.
4	Blade	Chop and mix the dishes.
5	Base	Support the container and hold the electric motor and resistance
6	Electric heating element	Provide the necessary heat to the container to allow cooking of the dishes.
7	Electric motor with rotating shaft	Rotate the blade.

For the design of the new food processor it was first of all necessary to divide the components into 4 parts:

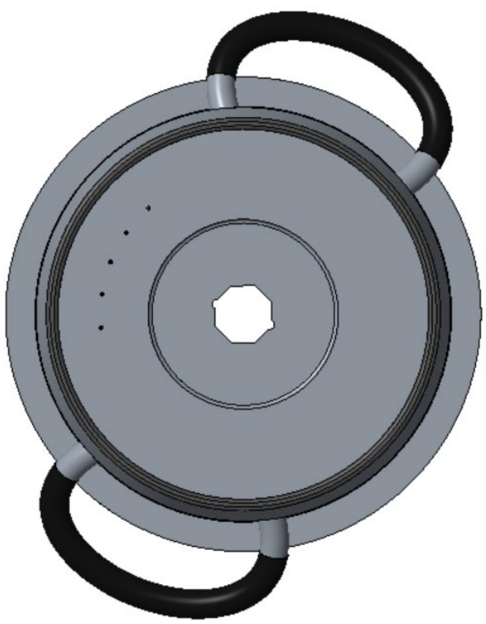
1. Container
2. Cover
3. Base
4. Components contained within the base

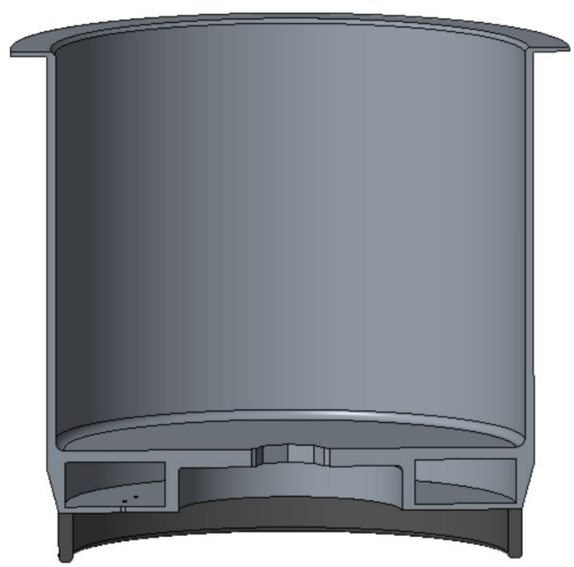
Each point saw the design of multiple components which were subsequently assembled. The end result is the assembly of all 4 parts.



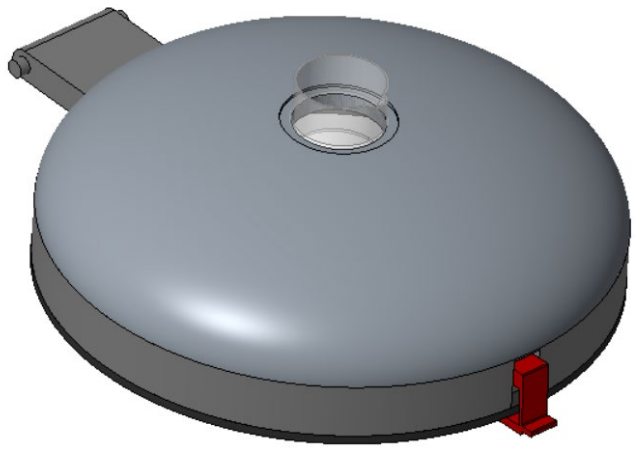
The pan was designed in such a way that it had a higher capacity than its competitors. The Benchmarking analysis showed that in order to obtain innovation, it was necessary to design a food processor with a capacity greater than 4.5 liters. The resulting pan has a capacity of 5 liters.

The pan has been designed with two handles to make it easier to handle, unlike some competitors that have a single handle. Two rubber coatings have also been provided to improve the grip and avoid possible burns.
It also highlights the housing for the electrical resistance and the hole for coupling to the electric motor.





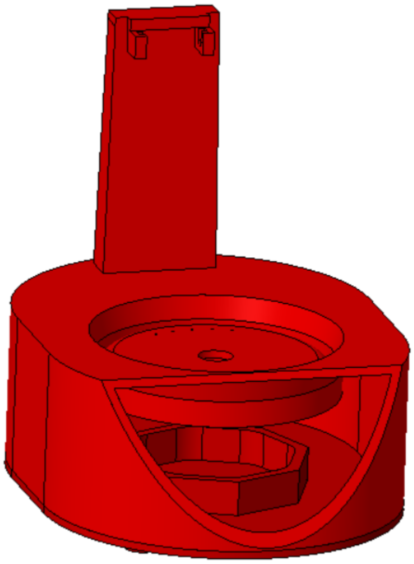
The cover is made up of a plastic cap, a plastic ring on which the measures have been taken so that the cover could be mounted, the lever for the opening / closing system, a rubber gasket that separates it from the container and finally a cap that occupies the hole made on the top of the lid.

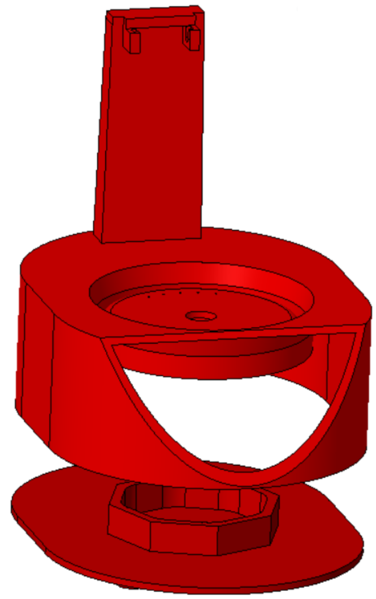


For the design of the cover it was necessary to pay attention to the relative opening/closing mechanism and to the coupling system of the cover with the base.
The cover has its seat in the base: the cover and base are constrained by a drive joint, which allows the opening and closing of the cover.
For the complete closing of the cover, a lever has been provided which, in closing mode, keeps the cover, jug and a gasket mounted under the cover compressed. The opening and closing of the cover is done manually. The lever has a tab that facilitates its use.

On the top of the lid there is a cap, which has been designed for a dual purpose: to occupy the hole on the top of the lid (made to allow for possible vents of steam) and act as a measuring cup to allow possible additions of ingredients into the container when the cover is in closing mode.

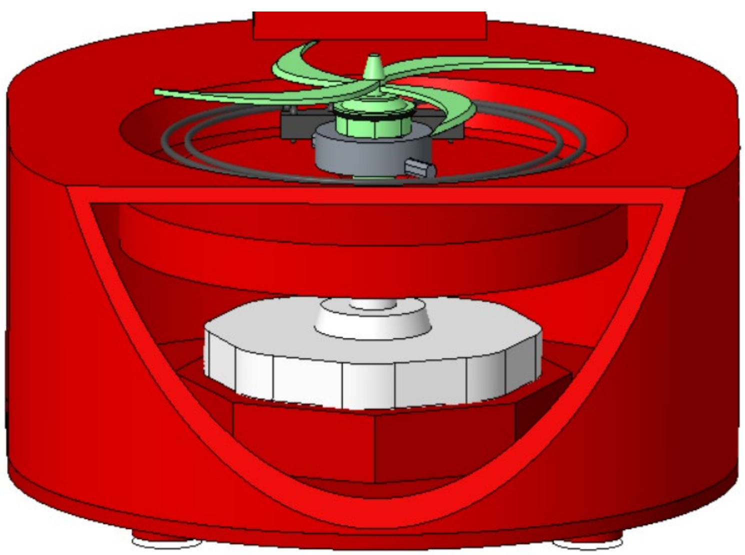
The base is designed to satisfy 3 functions:
1. Support the container.
2. Sustain other components (electric motor, resistance, scale, blade, screen).
3. Be functional for the assembly of the cover.

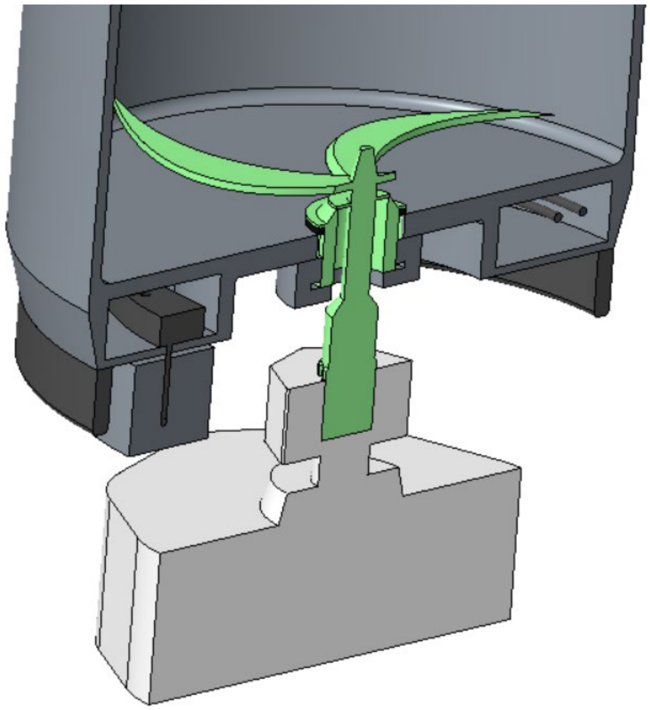




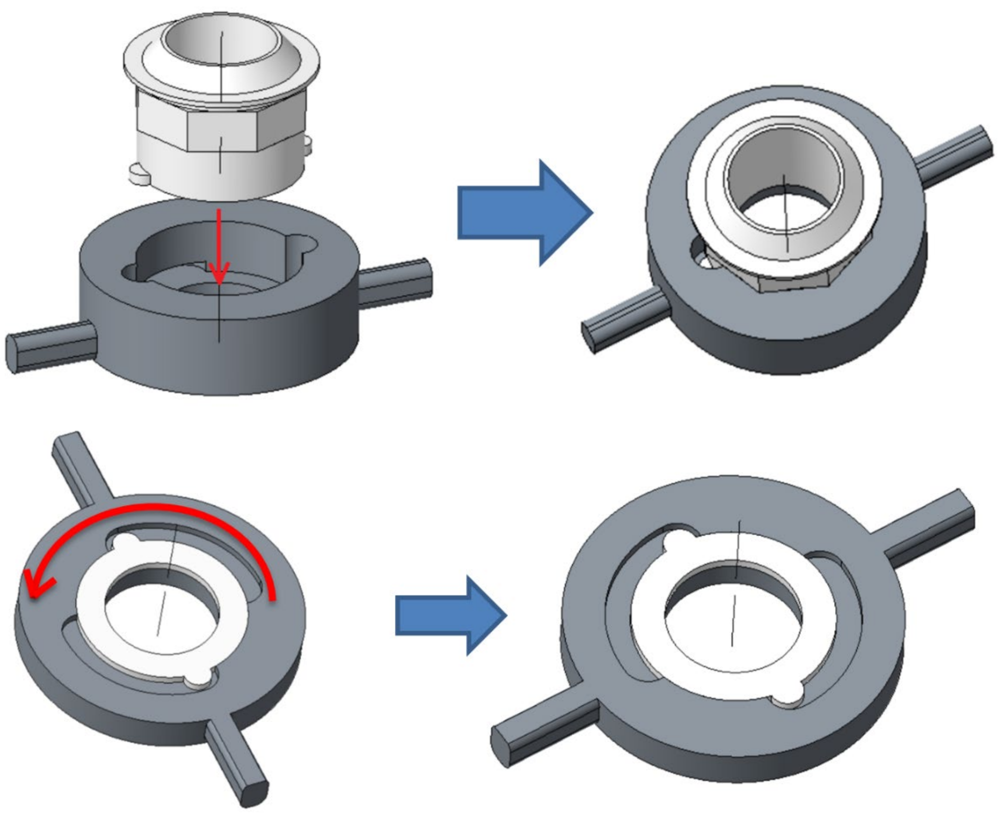
The elements that find support in the base are:

- Electric motor.
- Blade with relative locking system.
- Electric heating resistance.
- Weight scale.
- Screen.

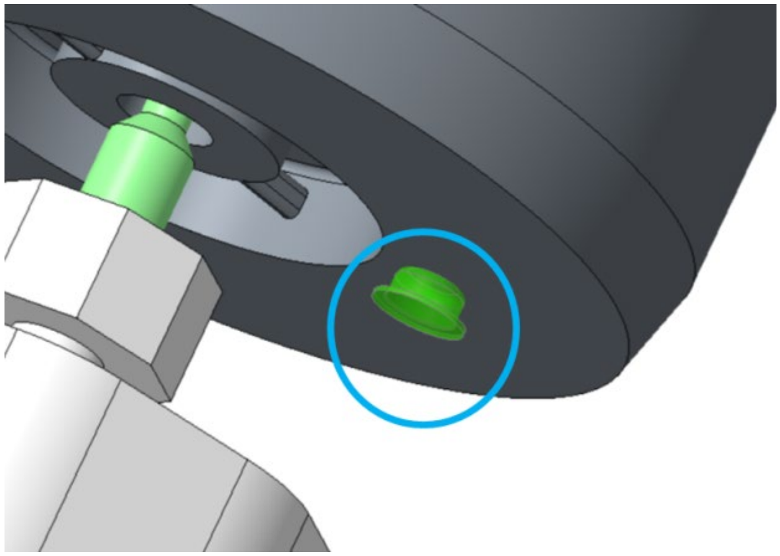




The blade is assembled to the pot through a ring nut system.



The housing for the integrated scale sensor is also provided.



7. Verify

The last phase of the path outlined by the DFSS methodology consists in verifying the success or otherwise of the project.
To evaluate the current state of the project, the *Benchmarking analysis* is resumed and the new food processor obtained from the design is inserted at the same time. As can be seen from the figure, only the values of the technical characteristics determined in the previous Design phase appear. A new comparison is proposed between the product just obtained and the TOP and FLOP values previously purchased.

Technical features	Value	FLOP	TOP
1. Engine power	550 W	70 W	550 W
2. Heating power	1600 W	500 W	1100 W
3. Touchscreen display	YES	NO	YES
4. Maximum temperature	180°C	100°C	180°C
5. Volume	5,00 l	1,2 l	4,5 l
6. Lenght	44,50 cm	41 cm	25 cm
7. Width	31,34 cm	46 cm	22 cm
8. Depth	41,34 cm	35 cm	24 cm
9. Weight	7,4 kg	10 kg	4 kg
10. Maximum time that can be set	120 min	30 min	120 min
11. Price	*To be evaluated*	1.299,00 €	190,00 €
12. Built-in scale	YES	NO	YES

For the choice of the electric motor it is decided to adopt the corresponding TOP value. The electric motor chosen thus corresponds to 550W of power.

The value of the overall weight of the object is obtained directly from the CAD model.

The maximum time that can be set is 120 minutes.

The choice to bring the maximum temperature that can be set to 180 ° C is given by the fact that at this temperature the conditions suitable for frying in vegetable oil are reached. The possible possibility of frying increases the multifunctionality of the product. In this way, the value of 180°C is chosen as the maximum temperature that can be reached by the new food processor. For frying, a maximum vegetable oil capacity of 4 liters is established.

To select the heating power, a simulation is carried out using the software ANSYS, under the following conditions:

- Pot material: AISI 405
- Ambient temperature: 20 ° C
- Convective coefficient in still air: 15 W / m² ° C
- Temperature on the faces inside the container: 100 ° C

Objective: to heat 5 liters of water up to 100°C.