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CONCEPTUAL DESIGN OF AN INNOVATIVE ELECTRIC TRANSPORTATION MEANS WITH QFD, BENCHMARKING, TOP-FLOP ANALYSIS

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Abstract

This article intends to apply some innovative design methodologies to define, as a first objective, an optimized technical specification and then, as a second objective, to manage the transition from conceptual design to construction project of an innovative means of urban transport, meeting the needs of ‘renewable energy’ requirements, which then declines into an hoverboard.

The methodologies used in this manuscript are the quality function deployment (QFD), applied in the first phase of the work to determine what is the appropriate means to move in the centre of medium-large cities; then it is used as a typical method for product marketing, i.e., the decision-making process driven by the analysis of benchmarking, suitable for quantitatively organizing competitive analysis and choosing innovation targets; finally, it is implemented the top-flop analysis in order to better improve the benchmarking implementation, identifying the best product in the market, basing on the highest number of innovative requirements owned by it [1-3].

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Keywords and phrases: QFD, benchmarking, top-flop analysis, city transportation means, renewable energy.

1. Introduction

With this article, we intend to set up the first strategic phase of the product development process, namely that relating to the conceptual project. In particular, this work refers to the setting of the project of an innovative means of transportation, green, sustainable, based on renewable energy, to move in the centre of medium and large cities.

The presented discussion presents a series of cutting-edge methods, in series of logical use, in order to make decisions both strategic and technical.

Among the inputs of the methods, we will have an analysis of customer requirements, competitive analysis, a series of technological objectives (or performances) as a result of the work-in-progress.

In particular, it will initially use the method quality function deployment (QFD), then the method of analysis of competition by benchmarking for detecting the quantitative requirements that will give us the possibility to realize an innovative product, empowered by a top-flop analysis to determine the number of requirements of the best product in the market, that will be the limit to overcome to embody innovation in a new project.

As for the QFD, the input values are the customer requirements, obtained through the method of "six questions"; then applying a QFD matrix interrelationship. There were obtained the outputs of the above-mentioned method, which represent the classification of all various urban transports, ranked according to user preferences.

The application of the method of analysis of competition, innovation-oriented, through the use of benchmarking is applied after the QFD.

The inputs are the quantitative specifications, i.e., the performance, of all the hoverboard models of all brands in the market. The output, however, is a comparison chart that contains all performance values for each model. Other inputs will be the table data, other outputs, the values (or the value ranges) for each performance, so as to achieve a technical specification with the quantitative targets to achieve an innovative product [4].

2. Why Applying Renewable Energy Innovation to New City Transportation Means?

Our way of life is closely related, among other things, to the mode of travel that we use to make our activities (work, leisure, study, etc.). We think we are right in car use, maybe even when there is not a real need. The car, which we much appreciate, owns in fact some positive sides (especially the autonomy), but, especially in urban trips, they are often overtaken by other important and negative elements suffered personally by the driver (lost time in the queue, difficulty and parking costs, etc.).

Nevertheless, there are also many negative effects suffered by the rest of the citizens, who may move without using the car. They suffer from the problems generated by traffic, even without having the benefit of making any movement in the car. These people suffer from the so-called “external costs”, i.e., those negative effects generated by those who use the road transport system but which are experienced by all other citizens, even by those who do not own a car.

Nowadays, traffic is an integral part of urban life affecting our habits, it takes time away from social relationships and emotions, it causes stress, and it is harmful to health. Everyday many people die in road accidents (including many pedestrians) and many more are injured. The social cost of road accidents is around 24 billion Euros. The pollution deriving from car reaps thousands of victims every year. In almost all big cities, the PM10 limits imposed by the directive on air quality are not met.

In addition to the social and environmental damage, we must also remember the economic costs related to the ownership and maintenance of private vehicles: on an average each household spends on the car about 5000€ per year in Europe. In addition, the economic value of time lost in traffic is an estimated figure on the order of billions of euros at national level.

The alternatives to cars are often unattractive. *Public transport* and *bicycle mobility* do not always have the attention they deserve by administrators, not only because of lack of resources but, very often, the appropriate specialist skills. In the absence of valid alternatives, the car remains the preferred means by many Europeans, despite many, in equal travel times, would be willing to use public transport. But today the share of journeys by *public transport* is lower than would be desirable, mainly because of poor ride comfort, optimal odd coincidences and infrequent connections. With regards the *bike*, it could be a real means of transport in the city for short distances (about half of all car trips in fact is less than 5km), but it fails to establish itself mainly because of the lack of safety conditions on the road, with the exception of countries like the Netherlands and Denmark [1].

Everything described above makes us to understand the need to develop an innovative means of transport, which overcomes the problems associated with traffic, pollution, lack of comfort, and being able to shorten transport times. Basically, it is needed to understand what means of transport will be the ones of the future for a future mobility.

So, the present work will develop a decision making process, based on QFD, benchmarking and 6σ, in order to identify the guidelines to design the ideal city transportation means.

3. QFD to Define the Best City Transportation Means: Six Questions

An innovative method to manage the flow of information, which normally accompanies the design phase of a product, is known as quality function deployment (QFD). If we want to turn the wishes of the customer, QFD method is suitable for this purpose, intercepting the real needs of users in the design requirements, suitable for all industrial needs, from applied research to product development, the establishment and production to distribution, from marketing to sales and related support services.

This method has been developed to take into account the technical prescriptions of customization of a product during the stages of product development and innovative production. QFD helps designers bringing out those desires, spoken and unspoken by customers or potential users, translating them into actions and projects, and then focusing on the various business functions, towards a common goal. The method can be synthesized as follows (Figure 1):

Figure 1. QFD development.

That can be deployed as follows:

1. Seeking the clients' requirements.
2. System clarification for quality.
3. Adding value for quality.
4. Customers' satisfaction following quality requirements.
5. Defining a strategy for competitiveness.

QFD starts with the *explanation of the task* that can be summarized as the following scheme (Figure 2):

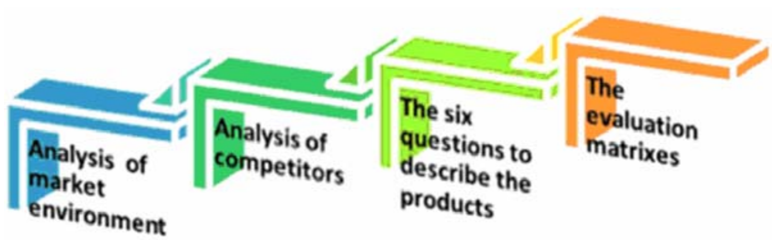


Figure 2. QFD: evaluation of the tasks.

After clarification of the task, by which technical requirements are defined, it is possible to start designing the product. The environment analysis and the six questions are both parts of the task clarification. In particular, *analysis of the environment* means understanding the positioning of the new product and its innovative requirements; *analysis of the competitors*' *products* means understanding the competitors' similar products and the way to improve them; then *six questions* help immediately to extrapolate those requirements that must be embodied by the object to be designed. They are (Table 1):

Table 1. QFD: six questions

QFD questions		Embodiment
a	Who	Who uses our product?
b	What	What is the use of the product?
c	Where	Where is it used?
d	When	When is it used?
e	Why	Why is it used?
f	How	How is it used?

Finally, speaking about *evaluation and interrelation matrices*, they usually can be used in a double way, i.e., to estimate relative importance or independence relationships among requirements. In the present work, instead, an interrelation matrix will be used for evaluating the best city transportation means based on green and renewable energy. It will be described in Paragraph 3.1.

3.1. Six questions application to innovative city transportation means (ICTM)

Applying the six questions to the case of the innovative city transportation means, the research team developing the present paper was able to give the following answers, in order to find out the requirements to be analyzed through interrelation matrix (Table 2):

(1) *Who*: *who uses the innovative city transportation means* (*ICTM*)? *Who produced the ICTM*? The ICTM is used by people: going to their job; moving in their city centre and in the traffic; avoiding many barriers; going to do shopping.

Requirements obtained after the discussion: use immediacy, agility, mobility, dexterity, access to the restricted traffic zone (A-ZTL), flexibility of use, accessibility to close spaces (ACS), accessibility to pedestrian spaces (APS).

(2) *What*: *what is the use of the ICTM*? The ICTM needs: to transport people; to go faster than on foot; to move in the city centre; to move in strict spaces; to be used for leisure; to go to job.

Requirements (after the discussion): capacity of transportation for driver and other people, superior speed than pedestrians, dynamicity, flexibility, fun, availability.

(3) *Where*: *where is the ICTM used*? It is used in the city centre, in close spaces, in traffic, in pedestrian areas.

Requirements (after the discussion): agility, mobility, access to the restricted traffic zone (A-ZTL), flexibility of use, accessibility to close spaces (ACS), accessibility to pedestrian spaces (APS).

(4) *When*: *when is the ICTM used*? It is used: in the morning for going to job; during the weekend for leisure; for going to do shopping; in alternative to go on foot.

Requirements (after the discussion): reliability, accessibility (A-ZTL, ACS, APS), flexibility of use, speed.

(5) *Why*: *why is the ICTM used*? It is used for: for going faster than on foot; for going farther than on foot; to avoid making hard; for arriving before; having good time; for not polluting.

Requirements (after the discussion): comfort, speed, use immediacy, fun, ecology, duration of use, autonomy, dynamicity.

(6) *How*: *how is the ICTM used*? It can be used: as a transport means; as a service device; in a security way (it can hardly be stolen, being transportable); in a flexible way (it can be used to access to close spaces, as for example: supermarkets and discount); in order to be able to transport and take it away.

Requirements (after the discussion): functionality, flexibility, self-transportability, not stealability.

Table 2. Requirements deriving from six questions analysis

Six questions	Requirements detected
Who	- Use Immediacy - Agility - Mobility - Dexterity - Access to the restricted traffic zone (A-ZTL) - Flexibility of use - Accessibility to close spaces (ACS) - Accessibility to pedestrian spaces (APS)
What	- Capacity of transportation for driver and other people - Superior speed than pedestrians - Dynamicity - Flexibility - Fun - Availability
Where	- Agility, mobility - Access to the restricted traffic zone (A-ZTL) - Flexibility of use - Accessibility to close spaces (ACS) - Accessibility to pedestrian spaces (APS)
When	- Reliability - Accessibility (A-ZTL, ACS, APS) - Flexibility of use - Speed

Why	- Comfort - Speed - Use immediacy - Fun - Ecology - Duration of use - Autonomy - Dynamicity
How	- Functionality - Flexibility - Self-transportability - Not stealability

The above presented analysis explains the twenty-two most important characteristics which the ICTM must own, that can be listed as follows:

1. Use immediacy. 2. Agility, mobility. 3. Dexterity. 4. Access to the restricted traffic zone (A-ZTL). 5. Accessibility to close (ACS) and to pedestrian spaces (APS). 6. Reliability. 7. Flexibility. 8. Speed in traffic. 9. Speed. 10. Duration of use, autonomy. 11. Functionality. 12. Not stealability. 13. Self-transportability. 14. Capacity of transportation for driver. 15. Capacity of transportation for other people. 16. Faster than pedestrians. 17. Dynamicity. 18. Fun. 19. Availability. 20. Comfort. 21. Ecology. 22. Price/cost.

4. QFD to Define the Best ICTM: Advanced Interrelation Matrix

As mentioned before, in the present work, an interrelation matrix is used for evaluating the best city transportation means, based on green and renewable energy, differently from the traditional uses that realize the application in order to estimate relative importance or independence relationships among requirements. Moreover, in the present application, the values assigned to each kind of transportation means to be evaluated are the following ones (Table 3) (differently from the traditional applications, where relative importance is evaluated with 0, 1, 2 and interdependence with 0, 1, 3, 9) (Freddi [2]):

Table 3. Dependence chart values

Value	Opinion
0	Poor
2	Inadequate
4	Insufficient
6	Sufficient
8	Optimum
10	Excellent

The interrelation matrix is shown below (Table 4); it is employed in a new way with respect to the classic ones traditionally used, as said before. Starting from the 22 *requirements* obtained in Paragraph 3.1, in interrelation matrix, they were linked to the *nine possible kinds of urban transport means*, i.e., the following ones: (1) on foot, (2) car, (3) motorbike, (4) scooter, (5) bicycle, (6) push scooter, (7) hoverboard, (8) bus and (9) taxi, emerged by a survey performed among a sample of citizens of medium dimensions city by the authors.

Table 4. Analysis of the best innovative renewable energy

	ANALYSIS OF THE BEST INNOVATIVE RENEWABLE ENERGY CITY TRANSPORTATION MEANS	ON FOOT	CAR	MOTORBIKE	SCOOTER	BICYCLE	PUSH SCOOTER	HOVERBOARD	PUBLIC TRANSPORT (BUS)	PUBLIC TRANSPORT (TAXI)
1	USE IMMEDIACY	10	2	4	6	8	10	10	2	2
2	AGILITY, MOBILITY	10	2	4	6	8	8	10	2	2
3	DEXTERITY	10	2	4	6	8	10	10	2	2
4	ACCESS TO THE RESTRICTED TRAFFIC ZONE (A-ZTL)	10	4	6	8	10	10	10	10	10
5	ACCESSIBILITY TO CLOSE (ACS) AND TO PEDESTRAIN SPACES (APS)	10	0	0	0	4	10	10	2	2
6	RELIABILITY	10	8	8	6	8	10	8	2	6
7	FLEXIBILITY	10	2	4	6	8	10	10	2	2
8	SPEED IN TRAFFIC	2	2	4	6	10	6	8	2	2
9	SPEED	0	10	10	8	6	2	4	6	8
10	DURATION OF USE, AUTONOMY	8	10	10	10	10	10	4	10	10
11	FUNCTIONALITY	10	8	8	8	8	6	8	6	6
12	NOT STEALABILITY	10	8	4	4	2	10	10	10	10
13	SELF-TRANSPORTABILITY	10	0	0	0	4	10	10	6	6
14	CAPACITY OF TRANSPORTATION FOR DRIVER	10	10	8	8	8	8	8	10	10
15	CAPACITY OF TRANSPORTATION FOR OTHER PEOPLE	4	10	6	6	2	0	0	10	10
16	FASTER THAN PEDESTRIANS	0	10	10	10	8	4	6	8	10
17	DINAMICITY	8	4	6	8	10	10	10	8	6
18	FUN	8	6	8	8	8	6	8	0	0
19	AVAILIBILITY	10	6	4	4	6	10	10	4	4
20	COMFORT	4	10	6	8	6	2	4	2	6
21	ECOLOGY	10	2	2	4	10	10	10	4	2
22	PRICE/COST	10	0	2	4	6	10	10	4	2
	TOTAL	174	116	118	134	158	172	178	112	118
	VOTE IN */10	7,9	5,3	5,4	6,1	7,2	7,8	8,1	5,1	5,4

The table above could be also explained in the following graphic (Figure 3):

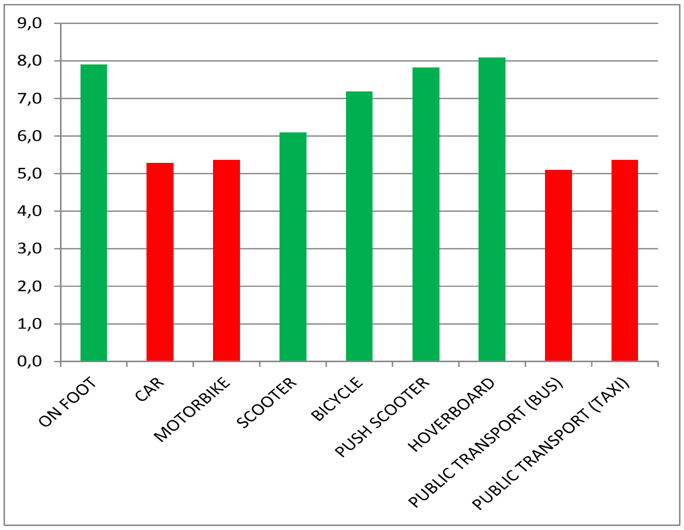


Figure 3. Histogram of analysis of the best innovative renewable energy.

From the analysis above, it can be remarked that, among nine kinds of city transportation means considered (i.e., on foot, car, motorbike, scooter, bicycle, push scooter, hoverboard, bus and taxi), the evaluation conducted among the students of University of Bologna takes us to the following considerations:

(1) Four means are not enough suitable for transportation in the city: car, motorbike, bus and taxi did not reach a sufficient vote for being considered as competitive means, in particular: car → 5,3; motorbike → 5,4; bus → 5,1; and taxi → 5,4. For arriving at this result, parameters linked to mobility, use immediately, flexibility, price, and alike were taken into consideration.

(2) Five means are suitable for transportation in the city, but only four (excluding scooter, voted 6,1) can be considered very good (vote over 7): on foot, bicycle, push scooter and hoverboard. Only hoverboard is excellent (over 8).

So, we can conclude that through an advanced QFD analysis, hoverboard was identified as the best kind of city transportation means. For this reason, our work will go on analyzing the hoverboards produced by the main competitors, in order to intercept the targets for innovation in this field (Sadok Cherif et al. [3]).

5. Benchmarking for Analyzing Competitors

Referring to what explained in the paragraph above, with this phase of the work, named benchmarking analysis, we will be able also to know:

(1) how many parameters considering for competitors analysis

(2) how many parameters considering for innovation

(3) what parameters are measurable performances

(4) what performances are considered top (the best ones)

(5) what performances are considered flop (the worst ones)

(6) computing for each kind of hoverboard, the difference top-flop

(7) intercepting the most innovative kind of hoverboard

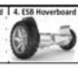
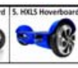
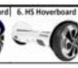
(8) defining the innovation targets specification for the new innovative hoverboard to be designed.

The benchmarking analysis results so strategical, not only to understand what are the hoverboards already in the market, but mostly to understand what it is necessary and compulsory to do to obtain an innovative product that could have success in selling.

Ten hoverboads were analyzed and sixteen technical and economical characteristics were found for each one; the identification names of them were changed for obvious commercial reasons. So they are identified with invented codes that we can find in the analysis below.

So, we can summarize all the requests above in the following table (Table 5):

Table 5. Benchmarking analysis

PERFORMANCES	1. RH Hoverboard 	2. ST3 Hoverboard 	3. ST1 Hoverboard 	4. ESB Hoverboard 	5. HXLS Hoverboard 	6. HS Hoverboard 	7. SMP 	8. PB Hoverboard 	9. SkX Hoverboard 	10. SOS 	INNOVATION TARGETS FOR NEW HOVERBOARD
Speed (km/h)	13	13	13	16	13	13	16	10	16	24	> 24
Battery Endurance (min)	60	90	90	120	60	82,5	60	360	90	30	> 360
Charging time (h)	1,5	1	1	2	1,5	1,5	3,5	2	1,5	3	< 1
Maximum weight of the driver (kg)	100	100	100	100	100	100	100	100	120	100	> 120
Hoverboard weight (kg)	12,2	10	10	14	10	10	17	12	13	11,4	< 10
Length (mm)	230	100	100	100	100	100	260	251	203	448	< 100
Width (mm)	620	584	584	584	584	584	544	615	600	182	< 182
Height (mm)	220	180	180	180	180	180	864	213	198	419	< 180
Max Power (Watt)	350	600	1200	800	1200	1200	1600	1200	700	1900	> 1900
Number of Engines	2	2	2	2	2	2	2	2	2	1	≥ 1
Led Illumination (YES/NO)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Led Display (YES/NO)	YES	YES	nd	NO	YES	NO	YES	nd	YES	nd	YES
Climb Degrees (°)	nd	30°	30°	18°	30°	30°	nd	nd	nd	nd	> 30°
Bluetooth for music (YES/NO)	NO	YES	NO	NO	YES	NO	YES	NO	NO	NO	YES
More riding modes (YES/NO)	nd	YES	nd	nd	nd	nd	nd	nd	nd	nd	YES
PRICE (€)	330,5	426,2	378,8	662,93	426,2	331,5	755,83	331,5	473,6	567,35	< 330,5

5.1. Benchmarking analysis: results

Ten models of hoverboard were kept into consideration; sixteen main characterizing performances were connected to each one. The hoverboards were named with imaginative names, in order not to infringe commercial issues. The performances indicated are the usual ones we can find on the sales brochures, both on internet and flyers.

Performances characterizing hoverboard are (Renzi and Leali [4]):

(1) Speed (km/h)

(2) Battery endurance (min)

(3) Charging time (h)

(4) Maximum weight of the driver (kg)

(5) Hoverboard weight (kg)

(6) Length (mm)

(7) Width (mm)

(8) Height (mm)

(9) Max power (Watt)

(10) Number of engines

(11) Led illumination (Yes/No)

(12) Led display (Yes/No)

(13) Climb degrees (°)

(14) Bluetooth for music (Yes/No)

(15) More riding modes (Yes/No)

(16) Price (€)

Some of them are measurable with a number and a unit of measure (indicated in parentheses), others are "Yes-No mode" evaluable.

All the performances (or requirements) are listed in a *matrix* (Table 5), in order to be linked to each model of hoverboard analyzed. For each line, referring to all the values of the same performance for all the types of hoverboard, we will highlight in green the best requirements, and in red the worst one.

The value in green becomes the target for innovation for a new hoverboard relative to that specific performance. All the innovation targets will be included in a column, at the right side of our matrix, entitled: "*Innovation targets for new hoverboard*". In this column, we can find all the best possible performances for a hoverboard, referring to what we have in the market.

However, it would be utopian thinking to realize a new hoverboard reaching all the sixteen targets, for many reasons: costs, times, technologies, etc.

So, it is necessary a further analysis that reveals us how many targets are necessary to be reached for achieving innovation.

5.2. Top-flop analysis

Top-flop analysis [5] is a method for arriving at innovation "with minimal effort" (Meuli and Raghunath [5]). In fact, this method counts the difference between the number of the best performances (named "top") and the number of the worst performances (named "flop") for each hoverboard; the value obtained after the difference between top and flop is the limit to be overcome for reaching innovation. Obviously, this value chosen for this limit must be the highest value among all the ten ones obtained for each model of hoverboard.

In our case-study, we can see that the limit for innovation in hoverboard is 7, that means that for realizing a new innovative hoverboard at least "*seven plus one*" performances must exceed the relative values in the column "*Innovation targets for new hoverboard*".

In our case, for achieving a new innovative hoverboard, we should improve at least 8 performances.

What 8 performances among the sixteen listed? We will try to answer the question, applying TRIZ method, that usually it is able to suggest the right architecture of a new innovative product [6-12].

Table 6. Top-flop analysis

PERFORMANCES	1. RH Hoverboard	2. ST3 Hoverboard	3. ST1 Hoverboard	4. ESB Hoverboard	5. HXLS Hoverboard	6. HS Hoverboard	7. SMP	8. PB Hoverboard	9. SkX Hoverboard	10. SOS	INNOVATION TARGETS FOR NEW HOVERBOARD
Speed (km/h)	13	13	13	16	13	13	16	10	16	24	> 24
Battery Endurance (min)	60	90	90	120	60	82,5	60	360	90	30	> 360
Charging time (h)	1,5	1	1	2	1,5	1,5	3,5	2	1,5	3	< 1
Maximum weight of the driver (kg)	100	100	100	100	100	100	100	100	120	100	> 120
Hoverboard weight (kg)	12,2	10	10	14	10	10	17	12	13	11,4	< 10
Length (mm)	230	100	100	100	100	100	260	251	203	448	< 100
Width (mm)	620	584	584	584	584	584	544	615	600	182	< 182
Height (mm)	220	180	180	180	180	180	864	213	198	419	< 180
Max Power (Watt)	350	600	1200	800	1200	1200	1600	1200	700	1900	> 1900
Number of Engines	2	2	2	2	2	2	2	2	2	1	≥ 1
Led Illumination (YES/NO)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Led Display (YES/NO)	YES	YES	nd	NO	YES	NO	YES	nd	YES	nd	YES
Climb Degrees (°)	nd	30°	30°	18°	30°	30°	nd	nd	nd	nd	> 30°
Bluetooth for music (YES/NO)	NO	YES	NO	NO	YES	NO	YES	NO	NO	NO	YES
More riding modes (YES/NO)	nd	YES	nd	nd	nd	nd	nd	nd	nd	nd	YES
PRICE (€)	330,5	426,2	378,8	662,93	426,2	331,5	755,83	331,5	473,6	567,35	< 330,5
TOP	3	9	6	3	7	5	3	2	3	5	
FLOP	5	2	3	5	2	4	5	4	2	4	
DELTA Δ	-2	7	3	-2	5	1	-2	-2	1	1	> 7

6. Conclusions

Innovative design methodologies were applied to define both an optimized technical specification and to manage the transition from conceptual design to construction project of an innovative means of urban transport, identifying an "Innovation targets list", through a benchmarking analysis (BMA). BMA was empowered applying top-flop analysis in order to define the limit of how many requirements are needed to achieve innovation.

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