

Article

Electric Bike Product Conception and Styling According to Design Trends

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Abstract: The following case study portrays the several steps required to conceive a product from scratch. The first step involves an in-depth analysis of today's electric bicycle market in order to obtain data and information relating to the levels of innovation and comfort required by customers. Then, we evaluate the implementation of a useful method to understand the level of innovation that the product must have to be competitive on the market. The second part studies the architecture of the product, considering the different components already sold on the market which will become part of the project. The third part concerns a comparison between different stylistic trends that the vehicle may have (in order to outline the best one). The fourth part concerns the CAD realization of the virtual model complete with all its parts, including a structural verification study of the frame. The last part studies the presentation of the product to the customer, exploring different effective ways to communicate what the strengths of the new product will be (also allowing them to customize it before its realization). The plan for the realization of the new product, starting from the concept to arrive at the final presentation to the customer, follows the methods proposed by applying a series of steps to develop a generic new product in an efficient, sensible, and methodical manner. Therefore, we will refer to quality function deployment (QFD), benchmarking (BM), design for X, until reaching the final prototyping and testing phases.

Keywords: electric bicycle; innovation; market; concept; architecture; QFD; benchmarking; SDE; design for X; rendering



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1. Introduction

1.1. Environment Analysis

Nowadays it is important for almost everyone to have a personal vehicle available for daily commuting. Whether it is for work needs, to spend free time outdoors, or to take your children to school, a vehicle such as the electric bicycle can be particularly convenient and necessary. This also allows you to release your available time from the timetables offered by public services [1,2]. This can also be seen as a challenge in favor of economic development and environmental sustainability, in terms of a better use of available resources, and in terms of a lower environmental impact [3,4]. As peoples' lives become more and more busy, and the streets also become busier and full of vehicles of any kind, the time it takes to travel is on average unexpectedly increasing [5]. It is easy to understand how the environment suffers from this in a proportional way, despite the constant attention to the reduction of emissions by the competent authorities [6]. From a totally and globally future-oriented perspective, it is evident that e-bikes represent a solution to all of these problems [7].

Contrary to what one might think, the electric bicycle is not a novelty of recent decades but much more dated. The first prototypes date back to about a hundred years ago [8]. Today, however, they are a source of investment for new companies and start-ups that are contributing to their spread on a global scale [9].

There are already existing regulations regarding the classification of electric bicycles and may vary according to the geographical area of reference. For example, in 2016 in England it was established that these vehicles can enjoy the same rights as normal pedal bicycles, provided they are equipped with an engine characterized by a power of less than 250 W [10].

1.2. Analysis of the E-Bike Market

Statistically, sales are expected to double compared to 2020 within the next five years [Figure 1] [11], despite the slight negative trend of recent times due to COVID-19. The sales forecasts see China as the main protagonist and, in general, the areas of East Asia [12].

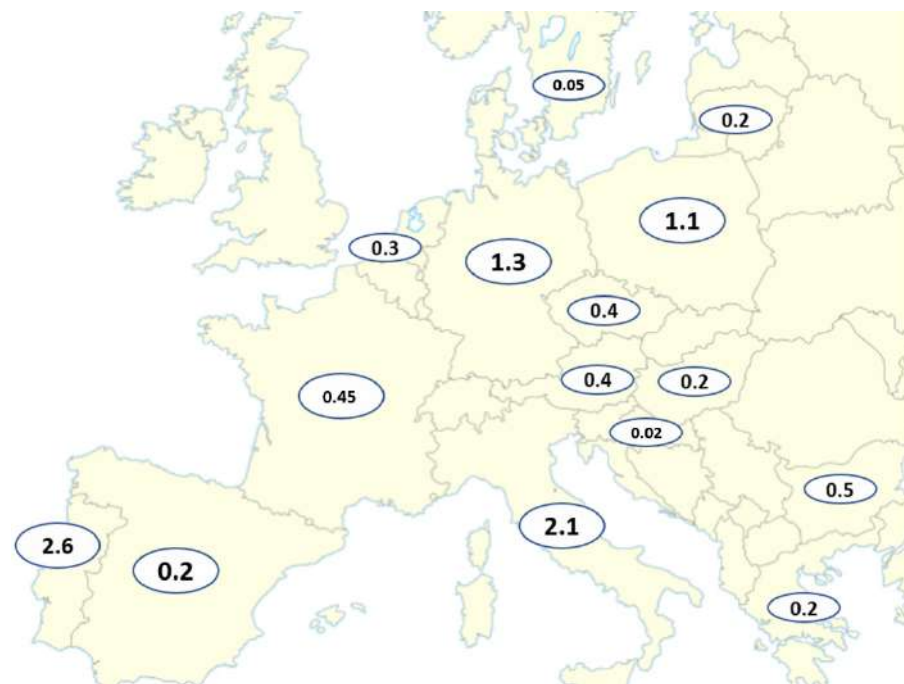


Figure 1. E-bike production in EU in 2020 (× million units).

Some of the best known and most commercialized e-bike brands are Trek Bikes, M1 Sport-technik, Giant Bicycles, Riese and Muller, Merida, etc. However, the European region represents around 39% of the e-bike market [13].

There is the greatest diffusion of e-bikes in the European context in Germany. In fact, many Germans consider the e-bike the most suitable means for their travels. Even if to a lesser extent than in Germany, e-bikes are now extremely popular in France and Italy. In European countries where the population prefers means of transport other than e-bikes, an incentive system is being implemented to encourage the purchase of electric bicycles (as for example in the United Kingdom) [14]. In previous years, many users used e-bikes for sport and leisure, but today they are increasingly used to moving quickly in urban traffic. The manufacturers try to make the product intriguing by focusing on aesthetic improvement, on the use of high-quality materials, and by making the batteries integrable in the frame [15]. In fact, each producer is interested in increasing its market share within a constantly growing sector by offering increasingly innovative and captivating products [16]. Europe undoubtedly dominates the e-bike market. However, this product is marketed in practically every country in the world, according to numerous variants described below. Even in cold countries such as Russia and Mongolia there has been an increase in sales of this product in recent years. This shows that a comfortable and ergonomic vehicle can be successfully sold even in geographically less predisposed areas for its use.

One of the most frequent perplexities of customers who are preparing to buy an e-bike mainly concern battery life. It is not possible to give a precise answer as autonomy depends

on many variables such as the battery capacity, the type of bike chosen, the trip to be made, the user's weight, etc. These factors just listed are just some of many factors and therefore, in fact, the number of kilometres that can be covered with a battery charge could fall within a very wide range [17]. Another common concern is in regards to the battery recharge time. The latter mainly depends on the capacity and quality of the battery. In any case, most of the batteries have a recharge time of at least a few hours at least. Charging a battery is very simple. In fact, you just need to connect the battery cable to an electrical outlet. The most widespread technology for e-bikes is the lithium-ion battery which guarantees a good capacity and low weight. One of the disadvantages of the lithium-ion battery is the susceptibility to temperature variations. In fact, the latter involve a variation in its capacity. A further disadvantage is due to the long charging times. As the number of recharge cycles increases, there will be a loss of capacity. The lithium-ion battery is currently one of many existing technologies that has the highest number of charge cycles [18].

Therefore, this study is aimed at assessing the market context in which the product will have to compete. Then, we proceed by evaluating which are the main characteristics that the e-bike will have to possess through a series of methodologies that are subsequently analysed in depth. Characteristics that define the engineering targets of the product components that will be part of the final model and preliminary choices for its commercialization. Only by establishing a good database obtained from these steps is it possible to proceed with the creation of the virtual model of the product and its development.

2. Materials and Methods

The proposed stages that outlined the proposed methodology in this study are summarized on Figure 2, which explains the performed steps in order to arrive to a virtual product prototype which is feasible to the market.



Figure 2. Methods used logical scheme.

2.1. Market Feasibility Assessment

2.1.1. Tool: Quality Function Deployment (QFD)

The QFD method widely used to portray a market analysis, that subsequently would allow to deploy a list of customer-driven characteristics. This type of analysis has been applied in all types of industries [19], and therefore this study aims to om automotive [20], chemicals [21], towards the food industry [22], and even information technologies [23]. Needs for a proposed service could be assessed regarding transportation [24], quality [25], and medical services [26]. Moreover, this method is based on the use of two main components: the six “wh-questions” (who, what, when, where, why, how) together with 2 valuation matrices, relative importance matrix, and dependence/independence matrix. The six questions are used to identify the client needs. Afterwards, the result is used to set up the matrix study. The relative importance matrix uses a range of numbers between 0 and 2, whilst the dependence/independence matrix uses a fixed set of values (0, 1, 3, 9), depending on the importance value resulted to each junction between line and column: 0 is assigned if the row requirement is more important than the column requirement; 2 is

assigned if the column requirement is believed to be more important; and 1 is assigned if they both are important.

WHO

Designed for daily commuting and therefore aimed at those who love to move quickly in the city without too much physical effort. Also intended for those who want to keep fit thus practising physical activity. Intended for all ages in compliance with current regulations (in the UK you must be at least 14 years old).

WHAT

The best quality requirements of customers: needing of a powerful and fast vehicle, low weight, safety, appealing design, comfort, ergonomics, low price, customizable, useful and smart accessories, space-saving, easy to use, easy and fast recharge of the battery.

WHERE

Urban and suburban roads. Cycle paths. Limited traffic area. States where there will be the development of communication routes suitable for bicycles.

HOW

On a technical level, the electric motor is powered by a battery and is controlled by a control unit that manages the additional thrust based on the reading of biometric and environmental values.

The values are provided in real time by a series of sensors that can be positioned externally on the frame or inside the components themselves. The sensors measure cadence (the number of rides per minute), the speed of the bicycle, braking (cut-off sensors). In the most advanced models also the effort, that is the pressure we exert on the pedals.

The battery has a variable autonomy depending on numerous factors such as speed, weight, terrain, steepness of the route, pedalling of the cyclist, time of use, delivery mode, etc. Depending on these factors, the power required to travel the routes varies.

WHY

Cost savings: insurance, fuel. Low cost of electricity. Eco-friendly, environmental interest. Fun, sport, free time. Commuting journeys. Need to have your own vehicle in the COVID-19 period. Avoid traffic. For those who need to move over small and medium distances in a short time. Moving without excessive effort thanks to the electric motor. Keeping fit. Government incentives.

WHEN

Seasonality: frequently used in spring, summer, autumn, less in winter. Mainly suitable for the summer but can also be used during the rest of the year. In your free time or for work and study trips that require a short time, so the product can be marketed in any season of the year.

2.1.2. Requirements Obtained

POWERFUL ENGINE/SPEED: the motor of an electric bike, by law, cannot exceed 250 Watts of power and the power supply is cut off when you exceed 25 km/h. The technical differences between the engines are limited compared to other means of transport. Depending on the consumer's needs, however, the most suitable motor can be chosen. An electric bicycle with a high mechanical moment (around 70–80 Nm) is suitable for steeper climbs, while lower values are satisfactory for circulation in cities (up to 40 Nm). The power is linked to the mechanical moment through the following relationship:

$$[W] = ([Nm] \times 2\pi \times [rpm])/60$$

LOW WEIGHT: an electric bicycle weighs more than a normal bicycle due to the presence of additional components such as the motor and battery. It is therefore important that the additional weight due to these components is adequately compensated for by the power they provide. It is preferable to have values as low as possible as this would allow you to use less power during the journey and therefore increase the autonomy time of the bicycle. In addition, a low weight improves ease of use. For example, if you are in a situation where you are unable to continue for a small stretch of the route, you can

continue with the bicycle by hand or lift it without excessive physical effort. Generally, a low weight-to-damage can be achieved with battery and motor performance.

SAFETY: travel safety depends on the effectiveness of the devices installed on the electric bicycle, their maintenance and the cyclist's caution. The main devices are tires that ensure good grip, stable handlebars, brakes, bell, lights, reflectors. The electric bicycle, more than the normal one, travels at higher speeds, so it is extremely important that the brakes are working well. For braking, an independent device is required for each axle that acts promptly and effectively on the respective wheels. They can both act on the wheel, on the hub, and generally on the transmission components. The brake can be operated by hand or by foot and the transmission can take place via flexible cables or hydraulic systems.

APPEALING DESIGN: a feature that the customer takes into consideration when buying a bicycle concerns its aesthetic appearance. There is a need to purchase not only a useful object, but also a beautiful one to look at. Designers must therefore guarantee the functionality of the bicycle by creating new and captivating shapes. Observing various models, the diversity in the shape of the frames, in the choice of colors, etc. catches the eye.

COMFORTABLE: the electric bicycle must be a convenient means of making short and medium-distance daily commutes, such as commuting from home to work or home to university, etc. Convenience also includes the possibility of reaching areas that would not be reachable by other means of transport without excessive physical effort. The electric bicycle, in fact, can travel on roads, cycle paths, and restricted traffic areas (ZTL). Furthermore, by using an electric bicycle you can avoid traffic and can be tied exactly where you want to go.

ERGONOMIC: the bicycle must be able to adapt to the characteristics of the user. In order to the cyclist to travel without assuming incorrect positions, the saddle must be comfortable, the height of the handlebars and the saddle must be adjustable. In addition, the shape and grip of the handlebar is of particular importance so that the hands, wrists and arms do not get tired during the trip.

LOW PRICE: the costs incurred by the user are mainly the price of the electric bicycle and the consumption of electricity. In the purchasing process, the customer will try to choose the product that best suits his needs at the lowest possible price. Electricity consumption is a few euro cents per kilowatt hour and is a cost that must be borne regardless of the electric bicycle the customer chooses; therefore, it is an almost negligible cost item.

CUSTOMIZABLE: customization allows the customer to design the bicycle he wants to be produced from the start. It has the possibility to decide the style, the components, the accessories, the shape of the frame, the colours, the type of motor and battery etc.

USEFUL ACCESSORIES: it can be useful for those who use the bicycle for sports or for excursions in their free time. They are electronic devices that can be speedometers, odometers, sensors that measure biometric parameters, etc. They are necessary to inform the cyclist of the remaining range, instant speed, kilometres travelled and any other data that you want to keep monitored.

EASY TO RECHARGEABLE AND FASTLY: to recharge the electric bike, you need to insert the charger plug into the power socket and connect it to the battery. The most used batteries for electric bicycles are lithium-ion and differ in size, weight, capacity, price and management system. To calculate the battery recharge time in hours, divide the capacity in ampere-hours [Ah] by the ampere [A] provided by the charger. Therefore, the greater the battery capacity with the same Ampere supplied, the longer the recharging time will be. On the other hand, a battery with a low capacity has a lower range. What makes batteries from different manufacturers comparable is their energy capacity, which is given in watt hours [Wh]. The higher the value, the more kilometers you can travel on one charge. However, generally a high energy capacity value means having a heavier battery. The range of electric bicycles depends on many different factors, the main ones being the energy capacity of the battery, the motor, the weight, the wind (for or against), the terrain, the steepness of the route, the age of the battery.

NOT BULKY: a space-saving electric bicycle is ideal for those with little space at home or in the garage, or for those who want to take it with them in the car or on public transport and allows for greater handling.

EASY TO USE: simple instructions, understandable and achievable by the whole population.

2.1.3. Independence Matrix

In order to understand which are the most independent characteristics of the product, a matrix has been created [Table 1]. Values from 0 to 9 have been assigned according to how much the characteristics in the rows depend on the ones in the columns. The four most independent characteristics of the e-bike are: smart, appealing design, ergonomics and recharge. The score values shown in the following tables was carried out in the initial phase of the project and may require the participation of all people directly involved in the project, from designers and engineers to potential future customers. Their opinion of the latter was obtained from initial surveys and market interviews. The methodology explained arrives until the point of accurate product conception and design born from a first market study; we have outlined the possibility of a second product acceptance assessment to be carried out once the product is finished.

2.1.4. Importance Matrix

The second matrix on Table 2 depicts the degree of importance of the selected customer requirements. To do this, a number from 0 to 2 is used to denote whether the row value is more important than the value of the column [27]. According to: 2 = the row element is more important than the column, 1 = both elements are of equal importance, 0 = the row element is less important than the column element. Afterwards, the values from each row are summed, and the property with the highest resulting value is therefore the most important one. In this case, the highest ranked options were ergonomics, price, and comfort (Table 2).

The same approach has been used to study the importance of the technical requirements of the product: values from 0 to 2 has been assigned to the characteristics in the rows, based on: 0 if the row is less important than the column, 1 if they have the same importance and 2 if the row is more important. The four most important requirements of the e-bike are safety, comfort, ergonomics, and recharge capacity.

2.1.5. What-How Matrix

The matrix shown on Table 3 is used to discover the features to highly focus on. The technical characteristics derived from the benchmarking analysis are in the columns, whilst the customer requirements derived from the QFD analysis are in the rows. A value from 0 to 9 according to how much each row can be satisfied by each column. This analysis arrived to the selection of row parameters recharge, price, ergonomics, and control. We chose these four characteristics as the key-points of our product.

Adding the values of the column features such as price, frame, weight, and suspension.

The highest-scored parameter was the frame, and this is therefore the main differentiating feature of the product. The goal was to create a new model of electric bicycle capable of offering desirable functionality and performance by the competition. Furthermore, the aspect relating to the aesthetics of the product was considered of fundamental importance; this is challenging to manage as electric bicycles often have similar shapes and appearances, offering little possibility of aesthetic innovation due to the constructive simplicity of this type of vehicles. It was opted for an extreme simplification of its geometries.

Table 1. Independence matrix.

	Power/Speed	Weight	Safety	Appealing Design	Comfort	Ergonomics	Price	Custom	Smart	Recharge	Space-Saving	Easy to Use	Total
Power/Speed		9					9	3		9	9		39
Weight	9		3	3			9	3		9	9	3	48
Safety	9			3	9	9			9				39
Appealing Design		9	3		3	3	3	9	3		3		36
Comfort	3	3	9			9		9	3	9	9	9	63
Ergonomics			9		9			9	3			3	33
Price	9	9	1	3	3	3		1	1	9			39
Custom	3	3	3	3	3	3	3		3	3	3	3	33
Smart		1	9	3	3	3	1	3					23
Recharge		9					9	3					21
Space-Saving	3	9		9	9		1	3				9	43
Easy to Use		9			9	9		3			9		39
Total	36	61	37	24	48	39	35	46	22	39	42	27	

Table 2. Importance matrix.

Requirements	Power/Speed	Weight	Safety	Appealing Design	Comfort	Ergonomics	Price	Custom	Smart	Recharge	Space-Saving	Easy to Use	Total
Power/Speed	1	1	0	2	0	0	1	1	2	1	1	1	11
Weight	1	1	0	2	1	0	0	1	2	1	1	1	11
Safety	2	2	1	2	1	1	0	2	2	1	1	1	16
Appealing Design	0	0	0	1	0	0	0	1	1	0	1	0	4
Comfort	2	1	1	2	1	1	1	2	2	1	2	1	17
Ergonomics	2	2	1	2	1	1	1	2	2	1	2	1	18
Price	1	2	2	2	1	1	1	2	2	1	2	1	18
Custom	1	1	0	1	0	0	0	1	1	0	1	1	7
Smart	0	0	0	1	0	0	0	1	1	0	1	0	4
Recharge	1	1	1	2	1	1	1	2	2	1	2	1	16
Space-Saving	1	1	1	1	0	0	0	1	1	0	1	1	8
Easy to Use	1	1	1	2	1	1	1	1	2	1	1	1	14

Table 3. What-how matrix.

	Price	Motor Torque	Wattage	Watt Hours	Charge Time	Distance Eco Mode	Distance Sport Mode	Frame	Suspension	Brakes Type	Weight	Maximum Speed	TOTAL
Appealing design	3	0	0	0	0	0	0	9	3	3	0	0	18
Comfort	3	0	0	0	3	0	0	9	9	3	9	0	27
Ergonomics	3	0	0	0	0	0	0	9	3	3	9	0	27
Price	9	3	3	3	3	3	3	3	3	3	3	3	42
Custom	3	0	0	0	0	0	0	3	1	1	1	0	9
Smart	9	0	0	0	3	3	3	3	0	0	0	3	24
Recharge	3	0	3	9	9	3	3	0	0	0	3	0	33
Space-saving	3	0	0	0	0	0	0	9	3	1	3	0	19
Total	46	13	16	24	27	24	24	66	37	29	52	24	

2.2. Benchmarking Analysis

To create an innovative product, a look to the concurrent models is necessary. The matrix on Table 4 has been created to show the main features of the concurrence’s products. 11 e-bikes have been studied, shown on Figure 3, and an innovative column has born. It is made of the best value for each row (technical characteristic), thus creating the ideal product. In parallel, a top-flop analysis on this matrix has been carried out. Looking at the best value for each characteristic, one point was assigned to the best product for that feature. Doing the same for the worst value and subtracting one point, we have summed the values for each model and a delta number was the result of the study. The best delta was that of Ride1Up Core-5 and Stromer ST1X, with a value of 2. The worst was that of Super73 Z1, with a value of −3. To create an innovative product, we need to design a model with more than two technical features better than the ones in the innovative column.

Table 4. Benchmarking matrix.

Brand	CUBE	CUBE	iGO Electric	Orbea	Rad Power Bikes	Ride1Up	Riese & Müller	Stromer	Super73	Yamaha	Innovation Column
Model	Kathmandu Hybrid Pro 625 Unisex	Town Hybrid One 400	Core Extreme 3.0	GAIN D50	RadRover Step-Thru 1	Core-5	Delite GT Touring	ST1 X	Z1	Cross Core	
Price (\$)	3999	2599	1899	2999	1699	1195	7479	4199	1395	2399	1195
Torque (Nm)	85	50	80	40	80	60	75	35	35	70	85
Wattage (W)	250	250	750	250	750	500	250	800	500	250	800
Watt hours (Wh)	625	400	624	250	672	624	500	618	556.8	500	672
Charge time (h)	11	4	5	3.5	6	4	4.5	4	4	4	3.5
Distance in eco mode (Km)	153	145	80	161	72	64	129	121	32	129	161
Distance in sport mode (Km)	48	64	48	42	40	32	56	64	24	48	64
Frame	Unisex	Unisex	Crossbar	Crossbar Carbon fiber	Unisex	Crossbar	Crossbar	Crossbar	Crossbar	Crossbar	/
Suspension	Front	Front	Front	Carbon fiber	Front	None	Full	None	None	None	/
Brakes type	Hydr	Hydr	Mech	Mech	Mech	Mech	Hydr	Hydr	Mech	Mech	/
Weight (kg)	26.4	24.7	33.5	11.3	32.4	22.2	28.5	26.7	31.7	19.7	11.3
Maximum speed (kph)	32	25	43	25	32	45	32	45	32	32	45
Top Flop	1	1	0	3	1	1	0	3	0	0	
Flop	2	2	1	3	0	0	2	1	3	1	
Delta	−1	−1	−1	0	1	1	−2	2	−3	−1	



Figure 3. Benchmarking models: (a) CUBE Kathmandu, (b) Super73, (c) Yamaha, (d) CUBE Town, (e) iGO Electric, (f) Ride1Up, (g) Riese & Muller, (h) Orbea, (i) Stromer, and (j) Rad Power Bikes.

3. Description of the Case Study

3.1. Product Architecture

The product architecture is a schematic image of the product that shows a 2D plant with all of the performances targeted from market and competitor analysis. In this phase we showed the handlebar of the e-bike and the possible battery locations. We chose to place the battery in triangle of the frame. It is the most common and logical position. Then, we looked at which battery and motor were the suitable for our product. Since weight and charging time were the leading feature, we chose the Bosch Active Line Plus as motor, and the Bosch Powerpack 300 as battery. Regarding the display, since another innovative aspect of our product is the connectivity, we chose the Bosch Nyon which enables one to install many high-tech software and apps.

3.2. Innovation

We decided to place on the bike a crash detection system that can send SOS message in case of emergency, similar to the proposal of Dabir et al. [28]. It is made of an intelligent fall sensor that, through connection to the dedicated app, sends an SOS message to the emergency numbers registered by the user. The device consists of a small precision detector and a free smartphone app. When the sensor detects an anomaly (combining data about position, rotation and acceleration), it sends a signal to the app, which displays a message for the user on the smartphone/display. At this point, the user has 30 s to interact with the app and in case of no interaction it automatically sends a distress request with the exact location thanks to the GPS location to all personal emergency contacts as well as to the members of the community in the vicinity. The community is made up of users who have the device on their bike or those who have downloaded the app and who have made themselves available in case of need through the dedicated function. Moreover, our product is designed to be smart. For example, it allows digital connection between riders by means of GPS, similar to the proposal of Lin et al. [29]. In addition, it could be developed to include maintenance tracking service on all of the components, such as tires, battery, motor etc. This is an outstanding parameter for the project, as on most of the bikes and electric bikes currently marketed lacks the capacity of connecting all users in an inter-communication network, making it both more fun to use and safer. using an avant-garde product such as this.

To sum up, we looked for innovation in four areas, deriving from the what-how matrix: charge time, frame, software and apps, and weight.

Concerning the battery charge time, we chose the Bosch Powerpack 300, with a charge time of just 2.5 h [30], lower than 3.5 h deriving from the innovation column of the benchmarking matrix.

Moving on to the frame, we decided to take aluminum as material due to its lightness. Moreover, the frame design is thought to be used by both women and men.

The third innovation is about connectivity. Thanks to the Nyon display [31] and suitable apps, many customizable options can be applied to the bike. It can be updated with new maps as well as it allows digital connection between riders through geolocation. In addition, it is possible to choose the riding mode selection, thus modifying the power supply of the motor and providing a more comfortable journey.

Finally, concerning the lightness, thanks to materials and design we managed to design a bike weighting only 12.5 kg, improving the best value of the benchmarking matrix (which was 13.5 kg).

3.3. Sketching

Here the preliminary sketches of the e-bike were made according to four different styles: natural, stone, retro, advanced. Each style was inspired according to the benchmark targets established. There are sketches for each: one is lateral, one is $\frac{3}{4}$ front, and one is $\frac{3}{4}$ back. In addition, we painted the background due to the fact that we think the environment in which we present the product could influence the product perception itself.

The retro style, seen on Figure 4, proposed a Graziella stile-inspired model. Thanks to its popularity in mass culture, it could be a good idea to be developed and improved. For this reason, it is one of the four stylistic choice that should be considered in the design process.

The second style proposal is stone, seen in Figure 5. It recalls some social culture established shapes of bike sharing service. It shows prominent lines and a significant size. Since weight is one of the leading features of our product, this version should be carefully optimized in order to have a competitive performance-to-weight ratio.



Figure 4. Retrò sketches.



Figure 5. Stone sketches.

This third style is the advanced one, seen on Figure 6. For some aspects it shows some similarities with the previous one, but with a strong limitation: due to its frame design, it recalls a typical men-suited bike. Since we want a product that can be gender transversal as much as possible, this solution must be abandoned.

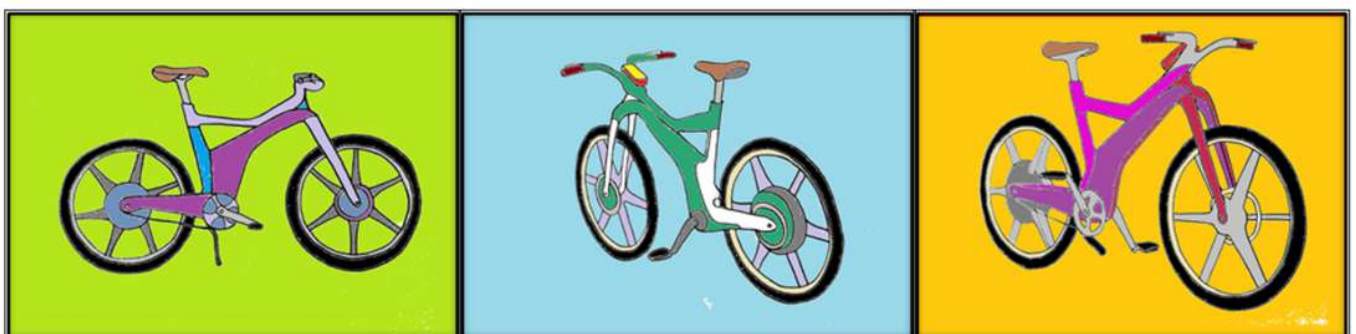


Figure 6. Advanced sketches.

The natural style here proposed on Figure 7 is a classic city bike, with a light frame, suspensions and the battery located on the lower tube. The trade-off between style and innovation is here optimized, to offer a comfortable product, but in line with the times. For this reason and the aforementioned ones, this style turned out to be the best option to create an innovative product.



Figure 7. Natural sketches.

4. Results

After the sketches, a more detailed view of the models is needed. This is carried out through the 2D drawings of the four bikes (one per style). In this phase, it is important to have a general view of the product, with the most important dimensions shown in the drawings. Therefore, we chose to develop the natural style, according to the customers' needs and the technical features deriving from the what-how matrix. Therefore, after the drawing, a CAD model of the bike frame has been developed (as seen in Figure 8).



Figure 8. Blueprint with main dimensions and CAD model of the e-bike.

Thanks to its shape, the product can be used by both women and men. All of the details related to the parts of this model, seen on Figure 9, have been studied as much as possible. A possible electronic device holder, useful in case the cyclist wants a display on the handlebar, was also modeled. This can be particularly convenient considering the safety of the product, as the display could offer a geolocation service useful for the cyclist to be found in an emergency. Additionally, the stylized bottle cage, the saddle, the handlebar with the grip areas, the wheels, the pedals, and the chain were thought to include quality materials and finishing. In addition, the installation of a quick disassembly and assembly system of the wheels was considered to transport the bicycle efficiently, allowing it to be quickly loaded on an alternative means of transport such as the car or a camper.

Another important aspect of the frame is the material. After having analyzed pros and cons of the most common materials, aluminum was chosen due to its cost and lightness. Going on with the work, an optimization of the frame was necessary, in order to minimize

the stresses on the model. After a static loads analysis, a simulation in Ansys showed a peak of 37 MPa in the lower area and a maximum displacement of 0.242 mm in the back. The finite element analysis was carried out by imposing the symmetry of the frame along the longitudinal plane, in order to speed up the meshing and calculation process by the software. Subsequently, Figure 10 shows a series of external loads acting on the bicycle frame were imposed: 1500 N of weight force on the saddle, 30 N and 50 N in the center of gravity of the battery and of the motor; in this way it is possible to simulate the physical effect linked to the structural deformation and to the stress of the frame due to the presence of the cyclist and of the two main components that allow the electric drive of the vehicle.

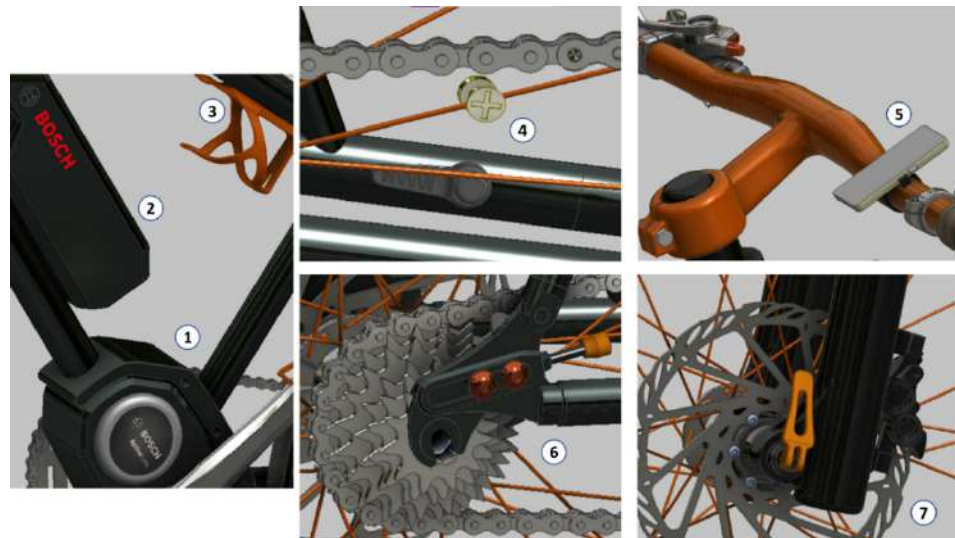


Figure 9. Detail parts of the model: (1) Bosch active-line electrical motor, (2) Bosh-branded battery pack, (3) stylish bottle holder, (4) speed sensor, (5) display holder, and (6,7) quick release system for the wheels.

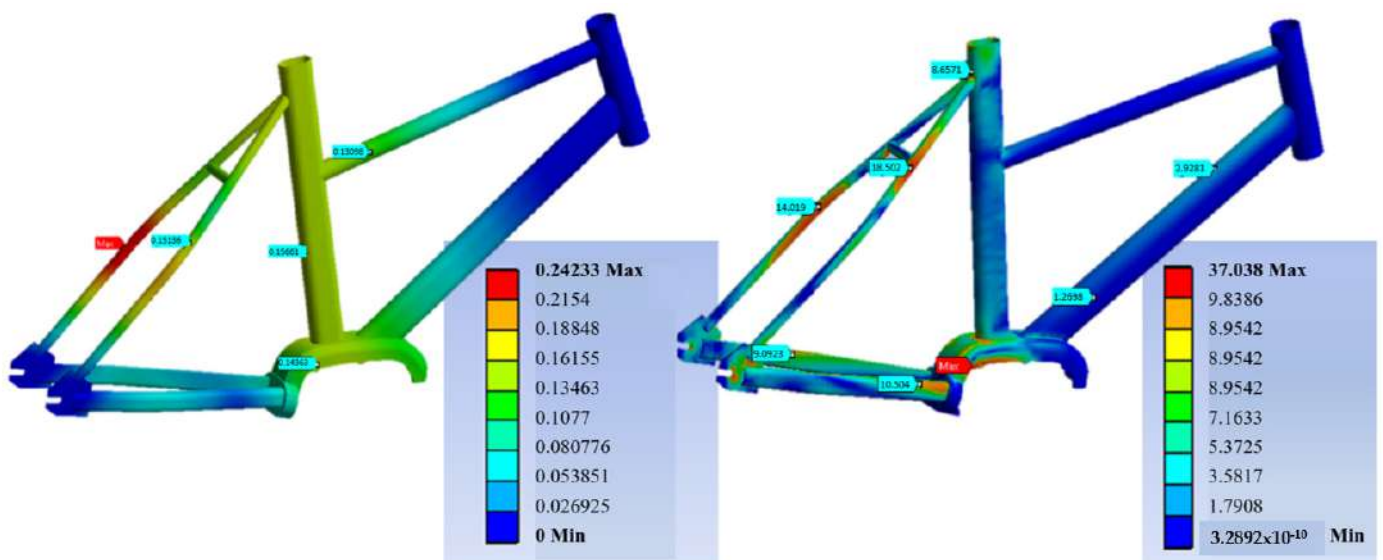


Figure 10. Fem results (displacements and stresses) evaluated on Ansys.

Once the virtual modeling of the product was completed, a final rendering was also created for an initial, physical prototyping [Figure 11]. It is conceived as an efficient method of presenting the finished product before it is even manufactured. Moreover, it makes it possible to customize some final characteristics such as the shape of some parts, the color,

the desired materials and so on, allowing the customer to instantly observe the effect of a different set-up. Being able to show the rendered product before its production is essential to understand how much it can be appreciated and at the same time customized from customer to customer.



Figure 11. Renderings obtained on Inventor.

The final rendering shown on Figure 12 was carried out making the most of the potential of Inventor Raytracing to obtain realistic lighting and shadow effects to the point of making the product seem real and tangible. Only in this way is it possible to optimally simulate the final appearance of the product materials, the reflection of some surfaces (using a multi-exposure HDR acquisition), and the positioning of the bike in a natural environment such as the one proposed. Lastly, the technical specifications of the proposed project carried out are shown on Table 5.



Figure 12. Final rendering of the product obtained using Inventor Raytracing.

The use of a CAD system at the base of the design process allows modifications of all kinds even after a first presentation of the product and an evaluation by potential buyers. For example, to increase the level of comfort offered using this bike, it was decided to add

a luggage shelf both at the front and back of the vehicle, as seen on Figure 13. The solutions that can be thought of are practically unlimited and it is necessary to investigate them in a relationship of direct dialogue with consumers. The level of product customization that can be achieved today is not even comparable to what companies could offer even just ten years ago. This is made possible thanks to the advances that computer aided design (CAD) systems technology has made and continues to make in recent years.

Table 5. Proposed product technical specifications.

Model	Material	Distance Saddle-Handlebar	Wheel Diameter	Wheelbase	Max Rider Weight	Max Speed	Weight	Range per Charge
E-motion	Aluminum	48 cm	69 cm	122 cm	150 kg	25 km/h	13 kg	40–100 km
Battery	Capacity	Charge Time	Motor	Power	RPM	Weight	Torque	Speed
Lithium-ion	300 Wh	2.5 h	Brushless	500 W	105	3.2 kg	50 Nm	25 km/h

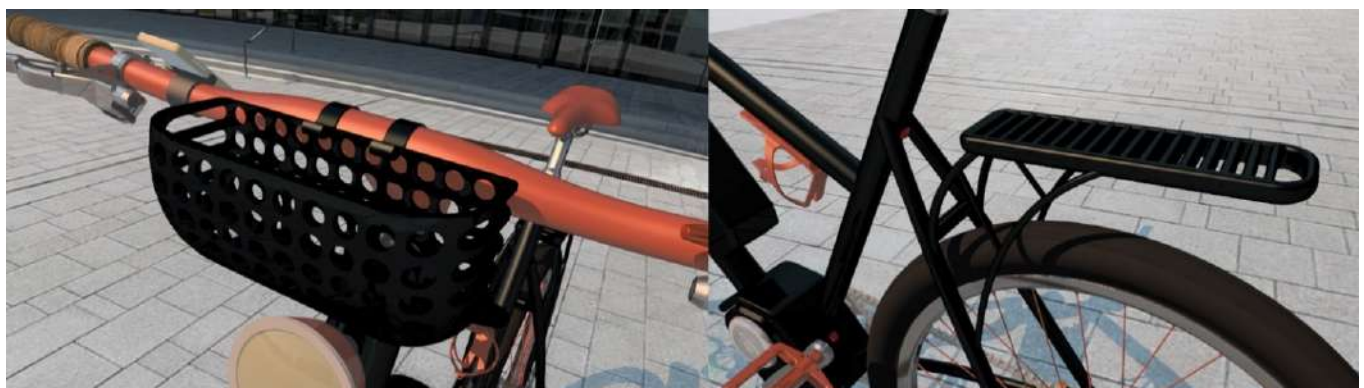


Figure 13. Addition of the luggage rack and the basket as a possible custom solution proposed by a customer.

5. Future Developments

Some of the most important devices of the e-bike are the battery and motor. The former accumulates energy and provides it when needed, while the latter gives force. One of the most challenging aspects in manufacturing this type of vehicle is providing the rider with the possibility to control torque and speed across many different conditions. Since the battery can store a finite quantity of energy, its efficiency must be optimized. In addition, another relevant feature is the weight of the battery. Increasing its size would mean improving the capacity. But, on the other hand, this would result in a heavier vehicle, therefore less comfortable and efficient. All of these considerations lead to the necessity to design carefully the right capacity of this fundamental tool. Moreover, another goal for manufacturers is designing e-bikes equipped with intelligent and functional tools, that could interact with displays, smartphones and smartwatches, requiring the least quantity of power. These and other features of e-bikes are the ones on which designers and manufacturers will need to focus on in order to keep creating innovative and better vehicles.

6. Conclusions

Developing a new product in the electric bicycle market is a challenge nowadays. The bicycle is a vehicle that has existed for years and over the course of history until now in which a wide array of products exists, offering different solutions depending on the target customer’s behavior. To innovate in this segment is particularly difficult on a product such as this. However, the QFD method described and applied in the previous paragraphs, made it possible to delineate in detail the design phases of the new prototype listed, making it possible to clearly derive how many and which technical and qualitative characteristics

it should have. Showing the product to the customer effectively is essential; augmented reality allows you to observe it in the real environment, allowing a better identification of the customer in using the product. The product rendering is instead essential to show him what the aesthetics of the product will be even after a possible customization process by the customer.

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