

## THE CONCEPTUAL DESIGN OF AN ULTRALIGHT ELECTRIC SCOOTER

**Abstract:** *It can be observed that today we live in a hectic environment, filled with lots of strict deadlines which we are obliged to meet by society standards. Today we have to be in a place at ten a.m. and one kilometer away at 10:05. Transportation is probably one of the most essential instruments of our success in modern society, and fits in the same category as skill. In this idea, the paper develops the design of an electric scooter having mechanisms used to improve the transportation and storage characteristics, and in the end the best solution will be proposed. There will also be presented some design ideas of three constructive solutions iteratively refined.*

**Key words:** *electric scooter, conceptual design, last-mile distances, personal transportation, storage.*

### INTRODUCTION

Commuting is something that we do every day. Be it for school, work or any other reason, we commute. Most of us use personal transportation, like cars or motorcycles, while other people use public transportation. Both these solutions have their advantages and disadvantages so let's look at a short comparison. Personal transportation is convenient in-transit, which means that it starts from a starting point and ends at the finish point with little or no deviation, which is something that public transportation does not provide. One can reach at destination easy and in comfort, but, in transit it will create pollution or traffic. In some cities, like New York it is much easier to get around using public transportation like underground metro or buses. However they create an issue, as neither the departure point nor the arrival point, at least for most people coincides with the stations used by the public transportation. The issue created by this is called "the last mile". This is a distance that people need to cover to get to their actual destination, somewhere between 800 meters (5 minutes of walking) up to 5 km. This distance is extremely important because it creates a new market. A market for people which want to use public transportation, like trains, busses and underground subway metro, as well as getting to their destination on time and in an easy way. It can argue that they could just use a bicycle, but it cannot take that on most trains or busses or metros. And if they could, what happens when they get to their destination? Leave it where? Outside? Exposed to the elements? Easy for someone to steal?

A new approach is needed. An approach that sees the issues that the average commuter faces with their "last mile". Up until a few years ago, kick scooters, skateboards, rollerblades were seen as toys. Some still view them today in the same fashion, but, no matter your point of view, you have to agree that they are effective at covering "the last mile". And the most effective of them all is the kick scooter, a platform that requires almost no learning curve whatsoever, is light, and most importantly is portable. You can carry it up the stairs, to your desk. You can take it with you anywhere. No more exposure to elements or to potential thieves. And you can go one

better, add an electric motor to the scooter, some batteries and your "last mile" distance can now become longer.

### 2. CONSTRUCTIVE ELEMENTS

An electric scooter is a small platform with two or more wheels that is propelled by an electric motor [1]. This definition is quite broad, allowing room for interpretation, and as such does not feature the same advantages as an electrically powered kick scooter (fig.1).



Fig. 1 Non-scooters that fit the semantics.

An electric scooter is a platform with two sets of wheels, mounted longitudinally along its axis, separated by the platform, where either one or both sets are powered by an electric motor and where the steering is done mostly by a pair of handlebars (fig. 2).



Fig. 2 Clarification pictures.

Today electric scooters mean to fill the gap that was created with the last mile distance, as well as to replace conventional modes of transportation like cars and

motorcycles. It could be argued that electric scooters are the size of motorcycles, or at least petrol-based scooters of yesterday, replacing them in the personal commute field (fig. 3).



Fig. 3 Left picture of Vespa GTS 300; Right picture of Gygabyke Groove.

However, big size brings with it the same problems as the systems they need to replace. This means that having you motorcycle outside in the elements is no different than having your big electric scooter outside with the elements. Although this is an emerging market it is targeting people that commute by bicycle/motorcycle/car, not the people who struggle with the "last mile" problem.

For these people a kick-scooter is great. Unless the distance that they need to cover is filled with climbs, potholes, or the users are generally not in shape. Electric assist is very important for these types of people.

However the market for covering the "last mile" is currently oversaturated with electric scooters that are copies of one another. Everything looks the same and most often than not, all scooters have the same specifications, the price being the only differentiating factor. However this oversaturated market creates huge competition. Currently there are over 100 electric scooter manufacturers in the USA alone. Adding to this China and we are looking at over a thousand manufacturers, each with various models. For a scooter to stand out from the crowd it has to have either a very low price or really good features.

Although a small price is nice, like the *pedal folding mini worker* you soon realise that a cheap scooter is a wrong decision (fig. 4).



Fig. 4 Cheapest electric assisted scooter, pedal-folding-mini-worker [2].

Reviews for 200-250 \$ scooters are so bad they are amusing. You soon realise that a cheap scooter is something that breaks as soon as you use it. More often than not, although they are sold with a warranty the company that produces them is a shell corporation, meaning that it doesn't exist. Therefore, you are stuck with a 200 dollars paperweight.

The electric scooters that are worth buying are the ones that meet your specifications in terms of quality of manufacturing, quality of the ride, range, power, portability, etc. You pay more for these features but at least you get your money's worth. At the end of the day, what you do is compromise.

As stated before, this is a new market. That means that there are no reputable brands or senior brands that you can refer to when buying a scooter. The best solution would be to buy from a brand into which a venture capital firm invested in. (Razor, Uberscoot, Zoom, Micro, Go-Ped, etc. – fig. 5) [3].



Fig. 5 Known brands Logos.

Another solution would be to invest into an emerging brand yourself. You can go on crowdfunding sites like kickstarter and find lots of potentially good products into which to invest [7].

The most important aspects of a scooter, at least for us are **portability, durability and ride quality**, in this order.

As **portability**, the weight and dimensions when folded are the key aspects. Although the weight issue can be solved quite easy, a key aspect that we see not addressed often is dimensions, particularly on the longitudinal side, where the scooter folds (fig. 6).



Fig. 6 Folded/Unfolded scooter.

It can be seen that longitudinally it barely changes dimensions, compromising the portability. We cannot carry it in a backpack; we have to drag it around like we would a trolley bag. That is all fine and well until stairs have to be climbed, or you need the use of both your hands to carry something.

As durability goes, we want an engine that is not overworked, a max weight of 150 kg, a chassis that doesn't bend or falls apart, and a battery that if we were

to use the scooter daily would last at least 2 years until it needs replacement.

On the route we want a smooth ride. A way to absorb the bumps is to use big fat wheels with inflated tires, shock absorbers or both.

### 3. TECHNOLOGIES

As stated before, there are no reputable brands. Therefore, a good measure of the quality of the brand is the technology put into the scooter. The features of the scooters are the only differentiating factors that a potential client has when making a purchase. The best features are presented below.

#### 3.1 The Hub-Centric motor

The placement of the motor into the wheel means that space is saved for more battery, while also allowing easy replacement if needed (fig. 7).

The motor can act as a regenerative brake as well, meaning that in case of a brake or downhill you can actually recharge the battery. The hub-centric motor is probably the biggest space-saver in a scooter. Another advantage is the fact that the motor can be placed on the front wheel.



Fig. 7 Hub-centric motor design (left), front wheel drive scooter (right).

That is not a particularly good placement due to having lower traction than on the back, but it minimizes the wiring required to operate the scooter.

The hub centric motor can be placed however on both wheels. Yes, the range diminishes but having double the power allows for traveling on difficult terrain, and climbing hills with no problem.

#### 3.2 The kick-assist

This was developed by Peugeot as an aid for the electric kick-scooter. It uses a circuit board linked to an accelerometer. It detects if you are kicking and speeds up to the speed that you kicked with. On the handlebars there is only a brake, wirelessly linked to this management system.

The advantage is that instead of carrying you, the scooter augments your movements, making the range higher and the experience more enjoyable. With the kick assist your speed doesn't decrease if you do not kick, it just increases when you do (fig. 8).

Combining the hub-centric motor with the kick assist feature you have a near perfect mode of transport for small distances.



Fig. 8 Kick-assist.

#### 3.3 Battery features

The battery is the most important aspect of the electric scooter. However it can do so much more. Like for instance recharge your phone or your laptop. Another cool feature is the fact that using solar power it can trickle-charge if you forget to plug it in when it is depleted. A lithium-ion battery that is trickle-charging constantly has a higher life expectancy (up to 20 years). Another aspect of batteries is the high density. Using the latest density figures, we can assume that inside a 20cm x 3 cm x 40 cm we can have a total capacity of 330 Wh (table 1). That means a 12 volt 3 amp/hour engine can run for 9 hours. Or charge the average phone 30 times.

Table 1

Projected battery density (approximation)		
Dimensions	200x30x400	$\pi \times 25^2 \times 65$
Energy density (Wh)	330 Wh	18 [3]

#### 3.4 Thoughts about the industry

The best designs so far are the Hyundai Motors Ioniq Scooter Concept (fig. 9).



Fig. 9 Hyundai motors Ioniq Concept Scooter [4].

This is a great scooter from the form-factor perspective. It is portable, has great technology, and as most good things was before it's time. Launched in 2017 to accompany the Hyundai Veloster hybrid, this scooter was intended to fit inside the central console of a car. Range is decent, the prototypes had approximately 7 km of range. The most impressive aspect is the simplicity. It measures 80 cm x 10 cm x 110 cm unfolded, but only 40 cm x 10 cm x 35 cm folded (fig. 10).



Fig. 10 Hyundai motors Ioniq Concept Scooter unfolded.

The issue with this near perfect scooter is the fact that it is still a concept, and might not see production anytime soon.

Another near perfect scooter is The MyWay Compact (fig. 11) [5].



Fig. 11 The MyWay Compact scooter folded/unfolded.

This is also a near perfect scooter, one you can buy today. The only issue we can see is that the platform defines the length. 65 centimeters is too much for carrying it in a backpack, reducing the size to about 40 would be ideal. This can be achieved using a telescopically platform (fig. 12).

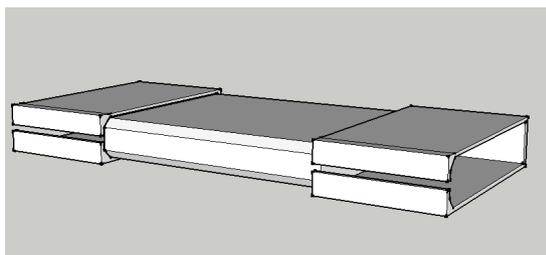


Fig. 12 Telescopically platform.

With this platform the size could go down to approximately 35 centimeters with no compromise over the battery or range.

The folding of the wheels on the side is a new and interesting design feature, a feature that should be implemented on more scooters.

Understanding the information presented we would like to build a scooter ourselves. First and foremost the most important aspect for us is portability. The scooter when folded will have as small as possible length, width and height. The best possible dimensions which ensure comfort are 40cm x 45 cm x 25 cm. As weight goes there should be a limit of 15 kg. The points of these dimensions are to be able to fit the scooter into a backpack, with room to spare. The second aspect would be that we would want modularity. Inside the chassis there should be wiring for being able to put two engines at each wheel. The height of the wheel should not exceed the width of the platform, and the width of the tire should not exceed the height of the platform. The handlebars should be telescopic to reach the user. The motor or the motors are hub-centric, and the battery fits inside the platform. It should be a simple design, one that is functional above anything.

#### 4. DESIGNING A NEW SCOOTER

In order to design a new scooter we have to first define the need of features that are required to be used in the scooter [6]. A scheme for the area of electric-powered scooter that could be folded up and carried easily is presented in fig. 13.

##### 4.1 The kick assist feature

The first feature that's worth implementing is the kick assist feature. This is basically a computer with accelerometers programmed to detect when the user pushes the scooter with the foot and match the maximum speed. In the same way it can reduce the speed of the scooter if the user puts the foot on the ground to increase friction, and by definition to stop the scooter. Now the reason why the scooter is benefiting from this feature is the fact that according to Newton's fourth law, there is basically no difference between a system that is stationary to one that is moving at a constant speed. Therefore, if the scooter only needs to keep a constant speed, rather than accelerating, the impact of the electric motors over the battery will be minimal, increasing therefore the range.

The kick assist is made to use a set of accelerometers; therefore it will detect the difference between uphill and downhill gradients, and adjust the power delivery gradually, in order to keep a constant speed. In lament terms, kick assist offers a constant speed, and in doing so uses less power, therefore increasing the range [7].

Another aspect of this feature that is worth mentioning is the fact that by design, the feature allows for safety. If you cannot push the scooter to a certain speed, then the scooter will not get to that speed. That means that you will use this complementary to your muscles and in doing so you gradually learn what speeds you are capable of handling.

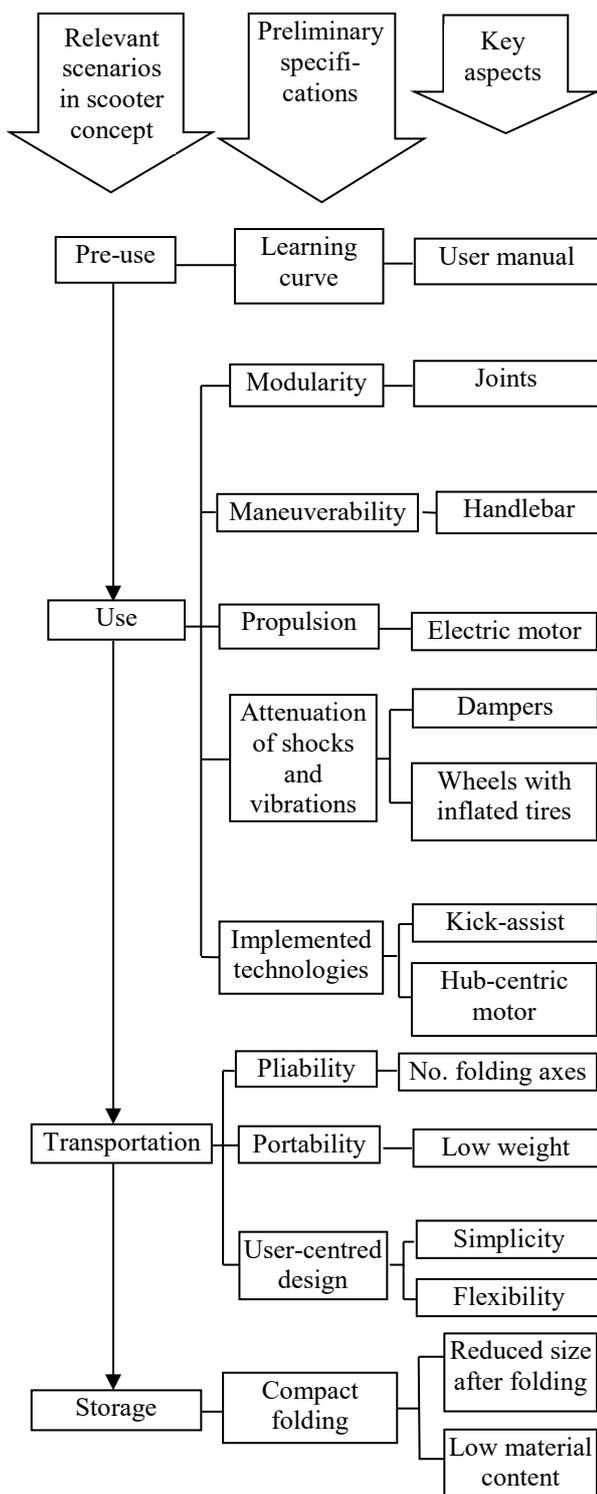


Fig. 13 Scenarios and key features in scooter design.

**4.2 The reduced weight in the motor(s)**

Basically, if the scooter is to be used from a standstill, the torque needed is 178 Nm, which, because there is no gearing, the engine needs to develop by itself.

So in order to hit a potential maximum speed of 50 km/h, from a standstill, the engine would require 3942 W of power in the time needed to reach 50 km/h, which is an enormous amount, even if the load would be split by two motors. But with kick assist, the motor(s) only needs to develop 17.6 Nm of torque, and a power draw of 390

watts of power per hour, the rest of the torque being made by the user’s muscles (fig. 14).



Fig. 14 Scooter using kick-assist feature [7].

The fact that the scooter has aluminum parts isn’t something new. However, except the handlebars, the steering fork, the S-bend, the scooter is made out of a 5 mm thick aluminum sheet, which is cheap and easy to work with, not requiring specialized tools, but is folded to be able to withstand the load of 150 kg (fig. 15).

Sheet sizes	Weight	Price (INR)
500mm x 600mm x 5mm thick - aluminum sheet	4.89 kg	₹36.57
625mm x 625mm x 5mm thick - aluminum sheet	6.08 kg	₹34.85
1000mm x 500mm x 5mm thick - aluminum sheet	8.76 kg	₹60.27
1000mm x 1000mm x 5mm thick - aluminum sheet	13.91 kg	₹92.73
1200mm x 625mm x 5mm thick - aluminum sheet	10.93 kg	₹84.88
1200mm x 1200mm x 5mm thick - aluminum sheet	21.47 kg	₹159.36
2000mm x 500mm x 5mm thick - aluminum sheet	14.65 kg	₹92.73
2000mm x 1200mm x 5mm thick - aluminum sheet	27.1 kg	₹164.88

Fig. 15 Prices and weight of 5 mm aluminum sheet [8].

**4.3 The battery**

Looking on the Amazon website, we found a battery jump pack that is not only very affordable, but is able to be discharged and recharged at a rate of 800 A/s. That means that any amount that the motor(s) need is take care of and even more. In addition to that, the battery is able to have a capacity of 32.5 Ah at 12 V (390W). Therefore, the battery can have the capacity needed for use of 1 hour. The battery is also Li-Fe which is one of the least polluting and environmentally friendly batteries, meaning that it can be easily recyclable (fig. 16).



Fig. 16 PowerAll PBJ32000R 24V Portable Power Bank and Vehicle Jump Starter [9].

The constructive solutions presented below have been iteratively developed. To get them, two methods of discursive character have been used, described in the literature [10] under the following names:

1. analysis of constructive solutions having contingency with the given problem;
2. iterative search for solutions [11].

In the first method, a decomposition of known constructions in terms of their functional structure and function carriers is made. Sub-functions performed by the scooter were derived from an existing configuration that led to the identification of the physical effects involved.

In the second method, an iterative succession of principle sketches was made, which started from a first idea (iteration 1) that was then modified and improved by eliminating the weak parts of conception. The iterative improvement continued until version 3, which largely satisfies the requirements list.

#### 4.4 Iteration 1

The purpose of the design was to exemplify how the platform folded, reducing the overall size. The front platform connects the handlebar to the rear platform. The total weight of the scooter is 18 kg, thanks to the DC motor that represents 35% of the total weight of the scooter, i.e. 6.3 kg (fig. 17).

The scooter folds in the desired volume of 500x400x300 mm. In the design one can see a single folding axis of the platform, a folding axis for each handlebar handle, and a telescopic handlebar axis (fig. 18). In use, the design allows for a high degree of user comfort thanks to the front shock absorber, rear absorber and large wheels with inflatable tires that absorb shocks and the elements of discomfort of the running track.

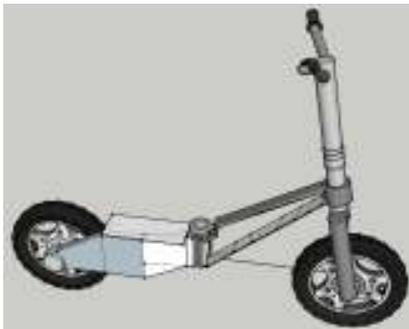


Fig. 17 First modeled version.

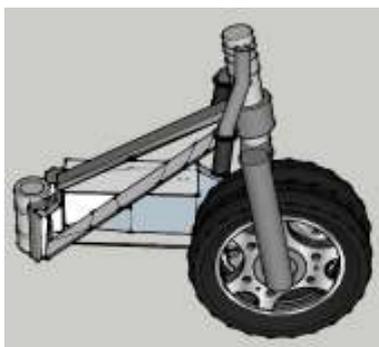


Fig. 18 First version of the folded scooter.

#### 4.5 Iteration 2

In this version the greatest improvement is the use of wheel-integrated motors. The folded scooter occupies a fairly small space of 400 x 250 x 120 mm, allowing storage in a backpack. There are 9 folding axes. Each handle can be folded down and the handlebars shaft is telescopic (fig. 19). Wheels are folded to 90 degrees. The hinge allows a folding axis of the wheel assembly at 180 degrees in the platform space. Thus full folding takes up much less space (fig. 20).

The platforms are secured with 3 securing clamps, both to provide a safety factor and redundancy. In the later version, the clamps have been abandoned for other gripping methods that allow safe fastening.



Fig. 19 Second version.

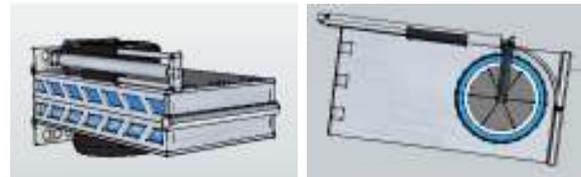


Fig. 20 Scooter completely folded.

#### 4.6 Iteration 3

The platform allows for 4 batteries, although some concessions need to happen to them, particularly in terms of the outer casings, as well as space for wiring (fig. 21).



Fig. 21 Scooter which meet the requirements.

But the biggest feature that the scooter has is the ability to be folded. Currently on the market there are very few scooters that when not in use take up so little space, but they made compromises on functionality, simplicity, and aesthetics. The scooter presented here makes no such compromises, by relying on a simple yet robust design, mated to the latest technologies. Therefore, the scooter will be able to be folded and put in a backpack, to be used anywhere from the floor of an airport to a forest track (fig. 22 - 28).

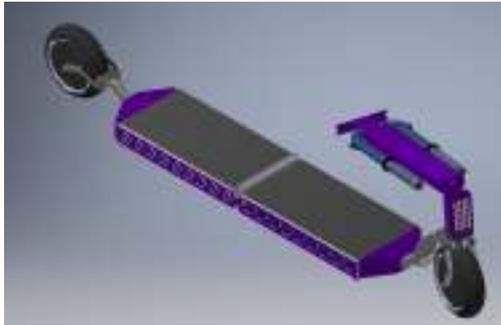


Fig. 22 Folded Handlebars.

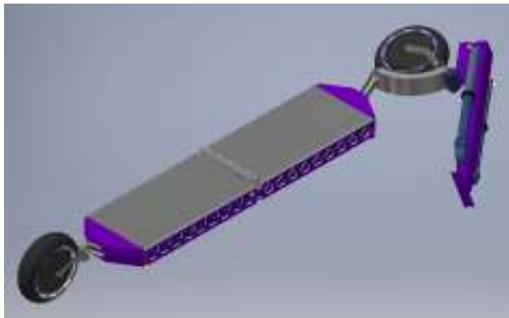


Fig. 23 Folded front wheel.



Fig. 24 Folded Front.

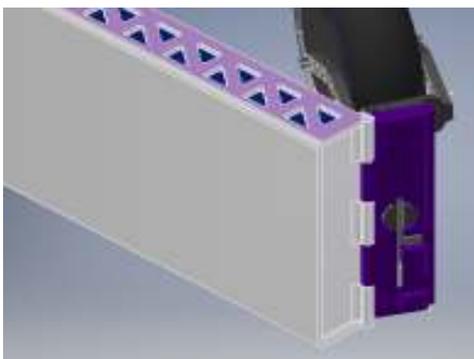


Fig. 25 Folding retention wheel mechanism.

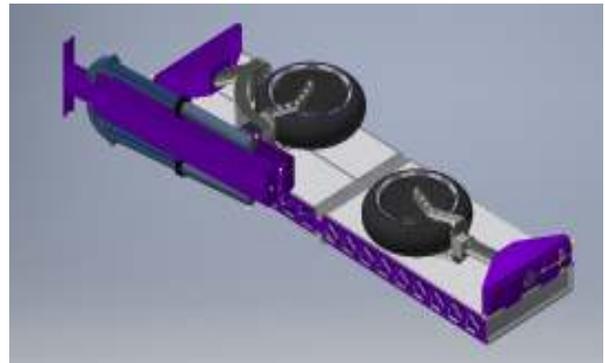


Fig. 26 Folded front and rear wheels.

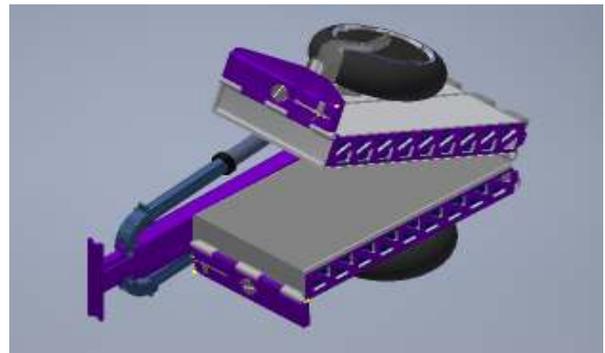


Fig. 27 Folded platform.

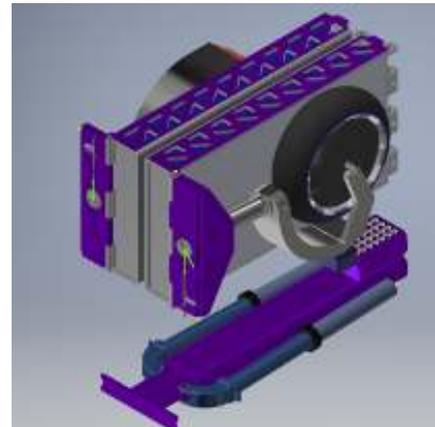


Fig. 28 Folded scooter

It can be seen that the handlebars are exceeding the designated constraints. If space is limited, they can be easily removable, and deposited in other places. It is noted that the top of the handlebars is a platform to deposit a smartphone so that in transit, telemetry from the scooter can be displayed (speed, battery level, etc). If a standard like in photography tripods is used, then the handlebars can potentially be used as a tripod or more to the case a monopod.

#### 4.7 The modularity

The modularity allows for limitless use case scenarios like the aforementioned forest track to more general use cases.

The implementation will be done using an online configurator that will allow potential customers to

configure the scooter to their specific use case. Also, the same web space will be able to house the ability to purchase various parts required to make the scooter (fig. 29). Therefore, even if very little money is paid at first, the experience does not need to stay the same, by being able to change any aspect of the scooter according to your preference.

The plan is that in time partners will come along on the project. The wheels at least are the 8 Inch format, so as long as there will be such wheels available, a way of purchasing them from the online store will be available. New batteries will allow upgradeability in time, as well as lower prices at the time of purchasing, some platforms coming with half of the batteries installed to allow the user to upgrade in time, while the rest of the options allow for personalizing (light, colour).

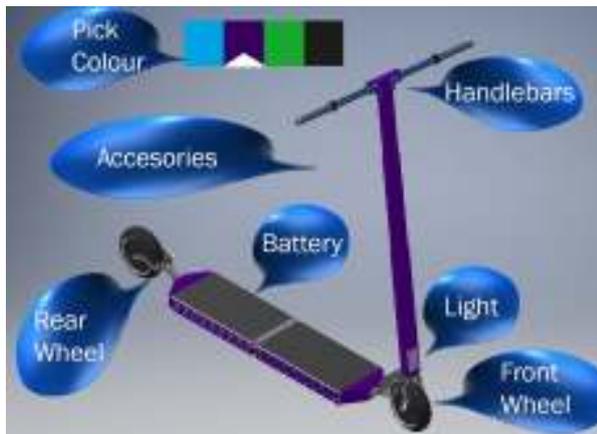


Fig. 29 Potential Online Configurator.

Accessories allow the user to choose the steering fork, the rear fork, the s-Bend, fenders, etc.

The modularity has another aspect on it, influencing the fact that scooters are configurable, the assembly will be different and so the cost of assembly will be higher. But through simple design, that cost will be zero as the assembly is handled by the consumer. Warranty is therefore handled on a part basis, and so the longevity of the scooter is ensured.

## 5. CONCLUSIONS

The main conclusion to be drawn by the design of this scooter is that portability in out-of-use scenarios in an area that needs to be worked upon. One of the potential benefits of the scooter is that it can be easily stored and transported. The design presented is a good way of looking at the problem, as it solves the issue that comes from storing the scooter on any period of time.

Another aspect to be considered and developed is the kick assist feature. In its crude form it works on flat ground currently, however by having two different accelerometers mounted in the exact same place on the battery platform, and in turn mounted longitudinally opposed along the scooter, at its extremities, the accuracy of the accelerometers and use of them is made much better, because the system has more points of reference.

In later models of the iteration presented, the scooter will have a companion app, which will be connected to the kick assist system, and so the system will have two computing points and three points of reference, and so having better accuracy and resolution in computing.

Finally modularity will make the scooter very desirable for mass use due to the modular design, which based on the partners willing to work with the manufacturer of the scooter will allow to almost limitless configurations and in turn increase the amount the users of the system (college students, urban commuters, factory and airport employees) will adopt it.

## REFERENCES

- [1] Electric scooter definition; [https://en.wikipedia.org/wiki/Electric\\_kick\\_scooter](https://en.wikipedia.org/wiki/Electric_kick_scooter) Accessed 10.06.2017
- [2] Cheapest electric scooter; <https://www.aliexpress.com/item/Electric-bicycle-electric-scooter-electric-scooter-pedal-folding-mini-office-worker/>; Accessed 10.06.2017
- [3] 5 Best Electric Scooters With ExtraOrdinary Features <https://www.youtube.com/watch?v=pCHhadsnKg8&t=1s>; Accessed 10.06.2017
- [4] Hyundai IONIQ; <http://www.hyundainews.com/us/en/media/pressreleases/47080/hyundai-motors-ioniq-scooter-concept-provides-first-and-last-mile-mobility>; Accessed 10.06.2017
- [5] My Way Compact; <http://newatlas.com/myway-compact-smallest-fold-up-electric-scooter/22475/> Accessed 10.06.2017
- [6] Kuang, C. (16 April 2009). "Convenience Is King". *GOOD Magazine*; Accessed 6.10.2017
- [7] <https://www.kickstarter.com/projects/flykly/flykly-smart-ped>; Accessed 12.12.2017
- [8] <https://www.themetalstore.co.uk/products/5mm-thick-aluminium-sheet>; Accessed 14.01.2018
- [9] [https://www.amazon.com/PowerAll-PBJS32000R-Portable-Vehicle-Starter/dp/B00STCW4PA/ref=sr\\_1\\_cc\\_6?s=aps&ie=UTF8&qid=1515856209&sr=1-6-catcorr&keywords=32000+mah](https://www.amazon.com/PowerAll-PBJS32000R-Portable-Vehicle-Starter/dp/B00STCW4PA/ref=sr_1_cc_6?s=aps&ie=UTF8&qid=1515856209&sr=1-6-catcorr&keywords=32000+mah); Accessed 14.01.2018.
- [10] Dobre, D. (2014). *Dezvoltare de produs-Baze teoretice și studii de caz*, Editura Bren, ISBN 978-606-610-117-2, București.
- [11] Ulrich, K., Eppinger, S. (2008). *Product Design and Development*, McGraw-Hill, ISBN-10:0-39-044050-7

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