Proceedings in Manufacturing Systems, Volume 15, Issue 2, 2020, 45-52 ISSN 2067-9238

GREEN, GREENER, GREENY. AN EVOLUTION OF GREENY TO A SAFER, MORE STABLE AND MORE CONFORTABLE ELECTRIC TRICYCLE

Albert SUVAC[1*], Lidia Florentina PARPALA[2], Radu Constantin PARPALA[2]

[1)] PhD Student, Robotics and Production Systems Department, University "Politehnica" of Bucharest, Bucharest, Romania
[2)] PhD, Lecturer, Robotics and Production Systems Department, University "Politehnica" of Bucharest, Bucharest, Romania

Abstract: *This paper is a presentation of Greeny's evolution over the design phases. The study started with an analysis of the existing products on the market, the requirements for such vehicles and the applied legislation in this case. There were mainly 3 versions of Greeny: V1.0, V2.0, V3.0. Each version brings optimisation in terms of autonomy, stability and ergonomics. The goal is to obtain a cost-effective product using mostly prefabricated parts having a high degree of recyclability. The evolution of different subassemblies (Handlebar, Fork, Folding System, Tilting System, The Hull, Rear Axle) is presented in this paper. Materials used for Greeny are also presented since we tried to lower the weight of the vehicle which influences its autonomy. For better damping, we have chosen for V2.0 and V3.0 a different type of fork which lead us to a change on the folding system that also is easier to be handled. The handlebar was changed to improve ergonomics and the safety of the passenger. It is also easier to be set to height. The safety of the passenger was considered also when the tilting system was changed. This change also brings a better posture on the vehicle. The hull design was decided by the position of the batteries that was changed to improve stability and ergonomics. A better feet position was obtained changing the design of the rear axle.*

Key words: *electric tricycle, safety, stability, design.*

1. INTRODUCTION

The history of electric tricycle goes back to 1881, when the first electric vehicle with two rear wheels and a front one was designed and produced by William Ayrton and John Perry in England [1].

Greeny started as a bachelor project in version V1.0 (Fig. 1). In this stage, most of Greeny's parts were subassemblies "borrowed" from bicycles or other similar products.

Current research has also tried to increase the autonomy and maximum speed attainable Greeny.

2. STATE OF THE ART

2.1. Similar products

For a better understanding we start by presenting some similar products existing on the market at this time. In Fig. 2 [2, 4, 8] one may find the main characteristics of such products. All the products presented have 2 rear wheels and one front wheel. The autonomy of the products is between 25 km, so, those are suitable to be used within a city range. The maximum speed varies from 19 km/h to 25 km/h. The frames of the tricycle are of aluminium in order to decrease the weight of the product which is usually around 30 kg, but it may be even smaller (as in the case of YikeBike the frame of which is also made of carbon and a smaller battery which leads to a smaller autonomy).

2.2. Greeny V1.0

The first model of Greeny (Fig. 1) had the frame made of steel bars which made it weight more (42 kg).

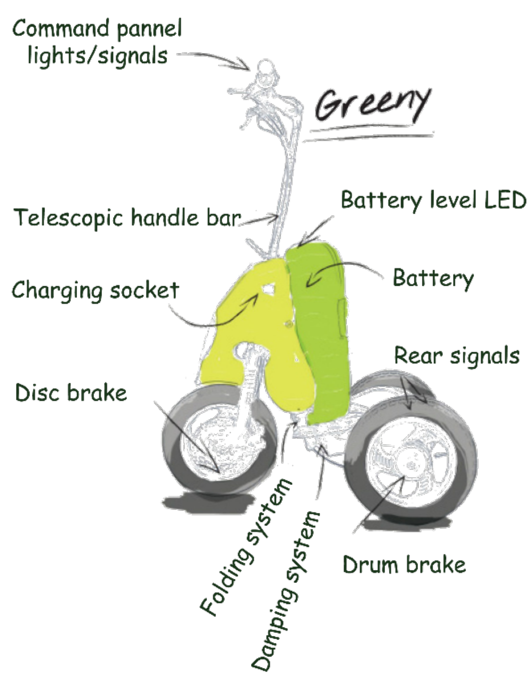


Fig. 1. Greeny V1.0 [5].

*Corresponding author: 313, Spl. Independentei, 060042, Bucharest, Romania
Tel: +40721853715;
E-mail addresses: *albertsuvac@gmail.com* (A. Suvac)

Characteristics / Product			
	Acton	**Qugo**	**YikeBike**
Frame	Aluminium	Aluminium	Aluminium/ Carbon
Maximum Passenger Weight	300 kg	120 kg	100 kg
Maximum Speed	19 km/h	25 km/h	23 km/h
Autonomy	24 km	25 km	20 km
Battery	Lithium Ion	Lithium Ion	Lithium Ion
Charging time	2h (fast charger)	2-3 h	1.5 h
	4h (normal charger)		
Weight	31 kg	34 kg	15.4 kg
Dimensions (LxWxH) mm	970x520x785 (Folded)	1150 x 580 x 780 (Folded)	660x490x580 (Folded)
	1020x655x1210	1150 x 580 x 1350	1040x640x825
Drive power	500 W	600 W	200 W
Weels dimension	24"	24"	20"
	3"	3"	8"

Fig. 2. Similar products [2, 3, 4].

The wheel configuration is 1F2R, meaning that it has one front wheel and two rear wheels (Delta tricycle). All three wheels can be tilted and have a 12 " diameter which is a plus for our tricycle, most of the other products having different diameters for the front and rear wheels.

The maximum weight of the passanger allowed for this version of the tricycle is of 300 kg.

Greeny's maximum speed was of 20 km/h for the version V1.0 and had 25 km autonomy given by a 36 V lead acid battery with 14 mA. The batteries charging time is 10 h.

Greeny V1.0 was compact compared with the similar products existing on the market having the following dimensions (L × W × H) [mm]: 500 × 592 × 910 (folded) and 910 × 600 × 1130.

This version of the tricyle is driven by a 250 W power motor mounted on the front wheel. This is a gear motor that produces more power by the fact that it is light and has small dimensions, but at the same time the friction is high thus creating a lot of noise and a degree of wear.

Following the analysis of the main characteristics of the most relevant electric tricycles on the market, the following aspects can be observed.

The tricycles predominate in the configuration with a front wheel and two rear wheels, usually inclined with maximum wheel dimension up to 24 inches, with their weight being between 15 kg and 64 kg. They usually have folding mechanism and can reach speeds up to 25 Km/h. They are equipped with a single wheel motor with a power output between 200–800 W.

The most common material used in their fabrication is the aluminium alloy with small exceptions when composite materials are used. The use of Lithium-ion batteries predominates, due to the reduced weight.

3. GREENY DEVELOPMENT

From the first version of Greeny to the current one there were a lot of researches made, which led to multiple modifications regarding the materials used for the frame, design of the handlebar, fork, hull and rear axle and also batteries and their placement on the frame.

3.1. Materials

Given the desire to reduce the total mass of the tricycle, in this stage of production of the prototypes, materials and manufacturing technologies that would allow the implementation of the prototype in a series production were considered, as resulted from the design studies, the ergonomics and resistance.

In the context of the large series production of the tricycle, each component was designed taking into account the usual technologies, found in a high-profile enterprise. Thus, each component of the tricycle will be described below in terms of the material adopted and the manufacturing technologies used for its practical realization.

In the assembly stage of the finished product, the use of existing technologies and usual assembly bodies was considered.

The manufacturing processes and technologies envisaged for each component of the tricycle will be briefly described below.

Greeny V1.0 and V2.0 have rectangular steel profiles for the frame construction, while V3.0 uses rectangular aluminium profiles (AL 6080) for the frame construction

Aluminium was chosen considering that:

- It has a third of the steel density which makes it lighter.
- It absorbs twice the energy that steel is capable to absorb which enhances the security of the vehicle.

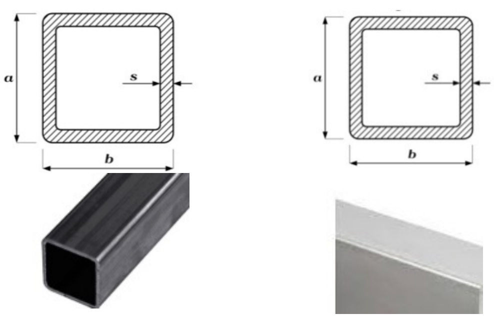
- It is fully recyclable.
- It can be easily machined.
- It can be casted in any geometry that is needed.

In Fig. 3, the profiles used for a) V1.0 and V2.0 and b) V3.0 are presented. The dimensions from the picture are 40 × 40 × 2 mm for all versions.

3.2. Handlebar

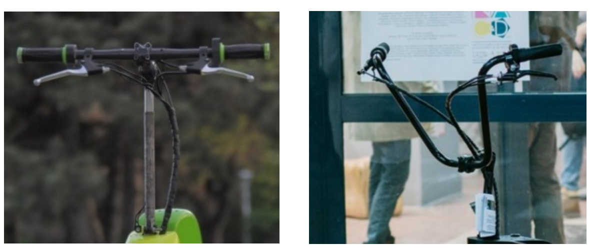
In the first version of the Greeny tricycle a foldable handlebar with a lockable type pin system was built (Fig. 4,*a*). The height adjustment of the handlebar and its folding is done using a telescopic system provided at the bottom with a clamping collar. At the top end, the handlebar is secured by an adjustable angle pipe.

For the second and third versions, a one-piece U-shaped handlebar was used (Fig. 4,*b*). Its folding is done by releasing the grip between the height adjustment system and the handlebar. Also, a cone-type locking system with a threaded bar was used to adjust the height and lock.



a b

Fig. 3. Materials: *a* – V1.0 and V2.0; *b* – V3.0.



a b

Fig. 4. Handlebar: *a* – V1.0; *b* – V2.0 and V3.0.

At the top end is fitted a pipe that allows the handlebar to be gripped and folded. Due to the fastening clamp, the fixing can be done without tools.

3.3. Fork

The first version (Greeny V1.0) uses a classic spring fork while the following two versions, including the current one, uses a fork with a viscous elastic cushioning, which helps to balance for a more efficient cushioning and improves the inclination.

Most tricycles on the market have a steering system in the form of a handlebar that allows the front wheel to be manoeuvred. All these mechanisms have the main function of making the rotation centre of the three wheels coincide at the same point.
Starting from the fact that a steering system will be used, it is necessary to determine the dimensions of each rod that make up the mechanism so that the centres of rotation of the three wheels are approximately the same (Fig. 5).

3.3.1. Fork arms. Greeny V2.0 fork arms are constructed of a 40 × 20 mm rectangular profile made from STEEL OL 37 with a length of 280 mm and are welded to the central part of the damping system, without assembly guides.

The arms are welded to the damping system. The inner wall of the upper arm is welded at an angle to the extremities of the central joint component. The joint used size is of 150 mm.

This folding mechanism presents a cumbersome operation that requires a lot of time and attention to position the two arms in parallel with no fixed point of support.

On the Greeny V3.0 variant the fork arms are constructed of three rectangular aluminium 6080 shaped components, cut at the ends at different angles thus obtaining an arm that follows the shape of the drive wheel. For welding/assembly purposes, a support point was created, by cutting the upper arms following the outer shape geometry of the joint central component. The joint used is 80 mm in size.

Fig. 5. Fork.

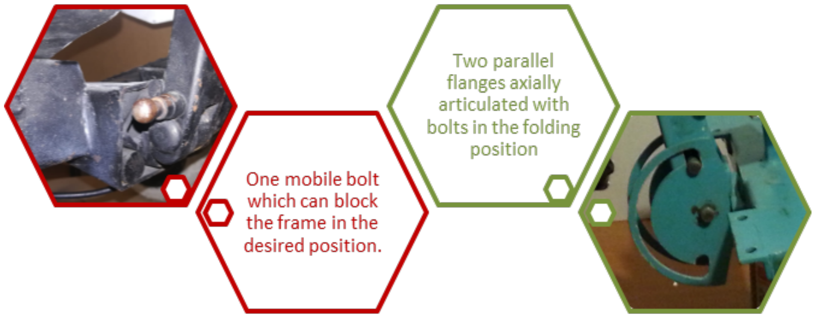


Fig. 6. Folding system.

3.3.2. Fork neck. In the case of V1.0 and V2.0, the fork neck was built welding two pipe profiles with different diameters.

For Greeny V3.0 the fork neck was built from an aluminium bar, worked on the lathe. The necessity for a machined fork neck was determined by the precision requirements for such a product. It offers a more precise assembly procedure and also makes the whole structure lighter.

3.4. Folding system

The folding system (Fig. 6) is a component that allows the tricycle to be folded. In its manufacture, the following steps were followed:

1. Choice of material, hot rolled black board EN 10051 and round pipe EN 10025;
2. The 3 mm thick metal sheet was cut with water jet at KRAUTZ company according to the execution drawings;
3. The two bolts for locking and sliding were processed by turning on universal lathe at the dimensions in the drawing;
4. The parts were adjusted to be prepared for welding;
5. The markings were placed on the welding table using welding pliers and auxiliary devices according to the chassis frame design and welded with electric arc;
6. The parts were mounted with electric arc welding in protected environment (MIG-MAG);
7. The chassis part was checked dimensionally and qualitatively according to the specifications in the execution drawings and it was admitted if it was a good landmark;
8. The mark was painted in the electric field, considering the colour palette.

After all the components had been produced, the assembly stage followed.

The folding system of V1.0 consists of two components:

- a fixed shaft which connects the rear frame;
- a movable shaft which can lock the position (operational or folded).

The assembly of the folding system of V2.0 and V3.0 is made up of two articulated flanges axially parallel with bolts in the folding position (Figure 6).

3.5. The type of batteries and their positioning

For the first and second Greeny versions lead batteries were used. Lead batteries have a large weight and size, which is why for the current version, Lithium-Ion batteries are used.

Also, for the first two versions the batteries were positioned on the frame, while for V3.0 the front fork was chosen to position them for a user's comfort increase and the future possibility of a saddle mount (Fig. 7). Another issue with the batteries positioned on the frame was that it created an instability moment when folded, tilting the whole tricycle backwords, making it difficult for the user to carry it. Another benefit with the batteries on the front fork is weight distribution on hill climbs, making the front assembly heavier, thus offering more traction, without the need for the user to shift its weight forward very much. This design makes the electric module a lot easier to assembly and service, all the electrical components being packed into the same hull.

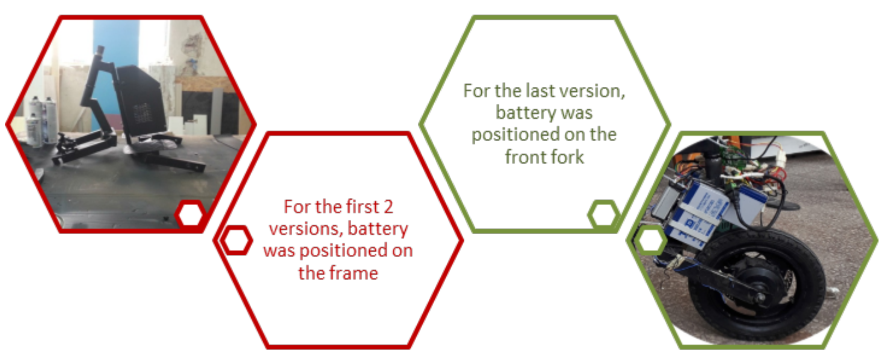


Fig. 7. Batteries.

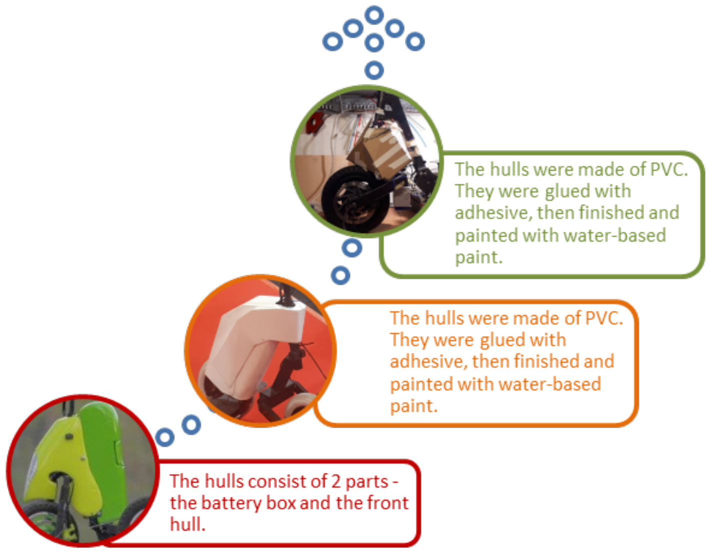
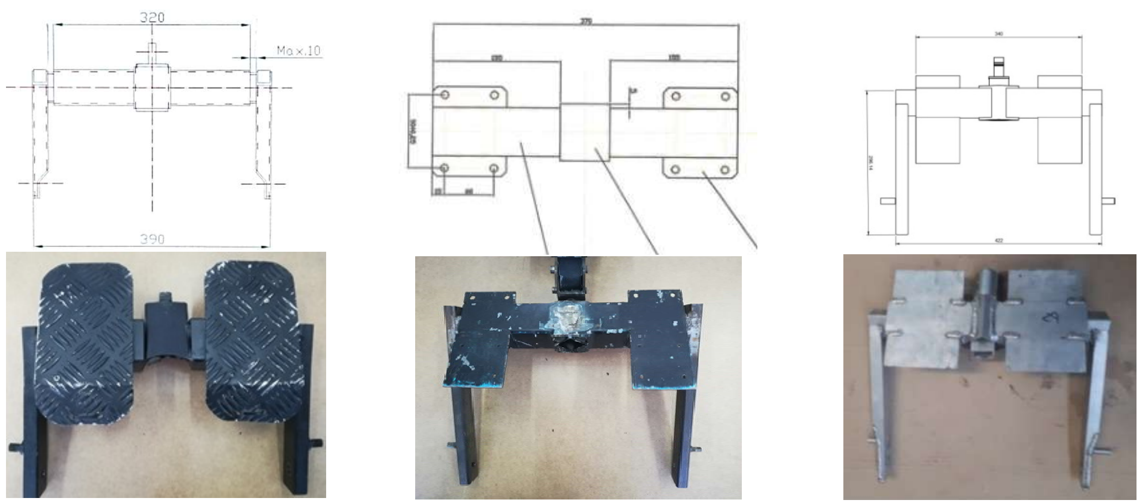


Fig. 8. Hull evolution.



a b c

Fig. 9. Rear axle: *a* – V1.0; *b* – V2.0; *v* – V2.0.

3.6. The hull

The hull of V1.0 (Fig. 8) was constructed of fiberglass by pouring it into a counter-mould using resin and glass fibre, after being finished and painted. The hull consists of two parts: the battery box and the front hull.

Toxic and non-recyclable materials were used for the first version of the hull.

Greeny V2.0 and V3.0 (Fig. 8) have the hulls made of PVC glued with adhesive then finished and painted with water-based paint.

3.7. Rear axle

The rear axle (Fig. 9) is the component on which the drive wheel and the shock absorber are mounted. The stages for constructing the rear axle are:

1. A rectangular pipe obtained by cold deformation was chosen; it was made of steel EN 10219.
2. The cross-section dimensions of semi-manufactured rectangular, round pipe, full bar and metal sheets are 60 × 60 × 2 mm, 40 × 40 x×2 mm, 40 × 20 × 2 mm 40 × 2 mm, 27 × 2 mm with the length of 6 m.
3. It was cut from the semi-finished bars having the required lengths with component dimensions from the drawings.
4. The bars were cut with the continuous band saw.
5. The parts were adjusted for welding.
6. The support shaft of the wheel axle was processed by turning on a universal lathe, at the dimensions of the drawing, after which the conformity was verified and the paint was applied.
7. After making all the parts, the assembly stage followed and it was performed according to the assembly scheme.
8. When assembling the joints provided with roller bearings, lubrication with special Metabond grease will be considered in order to reduce friction and make it more efficient.

9. The same thing will be done at the level of the wheel bearings also for the same purpose, namely for reducing friction.
10. The assembly of the depreciation elements is done according to Knott's technology

Greeny V1.0 has a wheelbase of 320 mm. It was designed that way in order for it to be more manoeuvrable through tight spaces. After several studies regarding the user comfort on the vehicle it was determined that a larger wheelbase was necessary, thus for Greeny V2.0 a bigger wheelbase of 370 mm was designed, increasing the whole tricycle sizes proportionally, and the general user comfort.

3.7.1. Tilt system

Vehicles with three wheels may be able to tilt in curves, like motorcycles, but for this phenomenon to be possible other types of physical and geometrical phenomena must be taken into account. For example, a vehicle with a wide chassis, at a minimum angle of inclination can reach the ground, which is why the behaviour of this type of vehicle, in a curve would not differ much from that generated by a classic car.

Another factor that has been taken into account for this tilting mechanism to be implemented is the shape that the arms will attach to the chassis, the wheels and how they will be assembled on the chassis, so that they can tilt as well in relation to it.

The tilt system in Greeny V1.0 and 2.0 (Fig. 10) is mounted between the 2 damping systems in the same plane, offering a more ergonomic support position for the user.

In Greeny 3.0 the tilting system (Fig. 10) is mounted between the two damping systems rotated at 45 degrees, offering greater resistance to increase the rigidity of the outer structure of the assembly.

3.7.2. Rear axle arms

The damping system arms, in Greeny V1.0 version, have a dimension of 280 mm.

On the V2.0 Greeny version the rear axle arms were made of steel rectangular profile with a 40 × 20 × 2 mm dimension having a 325 mm length. The arms are welded to the damping system without a guide system for assembly.

The arms of the damping system have a dimension of 150 mm.

The V3.0 Greeny version rear axle arms were made of a rectangular aluminium 6080 profile with a dimension of 40 × 20 × 2 mm with a length of 325 mm These are provided with a guide system for assembly / welding.

The rear axle is the component on which the drive wheel and the damping system are mounted (Fig. 11).

1. A rectangular pipe is used obtained by cold deformation, made of steel EN 10219.
2. The semi-finished product types are used - rectangular, round pipe, solid bar, metal sheet having the cross-section dimensions of 60 × 60 × 2 mm, 40 × 40 × 2 mm, 40 × 20 × 2 mm, 40 × 2 mm, 27 × 2 with length of 6 m.
3. It is cut from the semi-manufactured bars having the lengths required to make the components, to the dimensions of the execution drawings.
4. The bars are cut with the continuous band saw.
5. The markings are placed on the welding table with the help of welding pliers and auxiliary devices according to the chassis frame design and weld with an electric arc.
6. The parts are adjusted for welding,
7. The support shaft of the wheel shaft is processed by turning on a universal lathe, at the dimensions of the drawing, after which the conformity followed by the finishing, painting stage is verified.
8. The assembly of the depreciation elements is done according to the technology of Knott company.
9. After making all the parts the assembly stage follows which is done according to the assembly scheme.

When assembling, the joints provided with roller bearings and lubrication with special Metabond grease will be considered in order to reduce friction and make it more efficient.

The same will be done at the level of the wheel bearings for reducing friction.

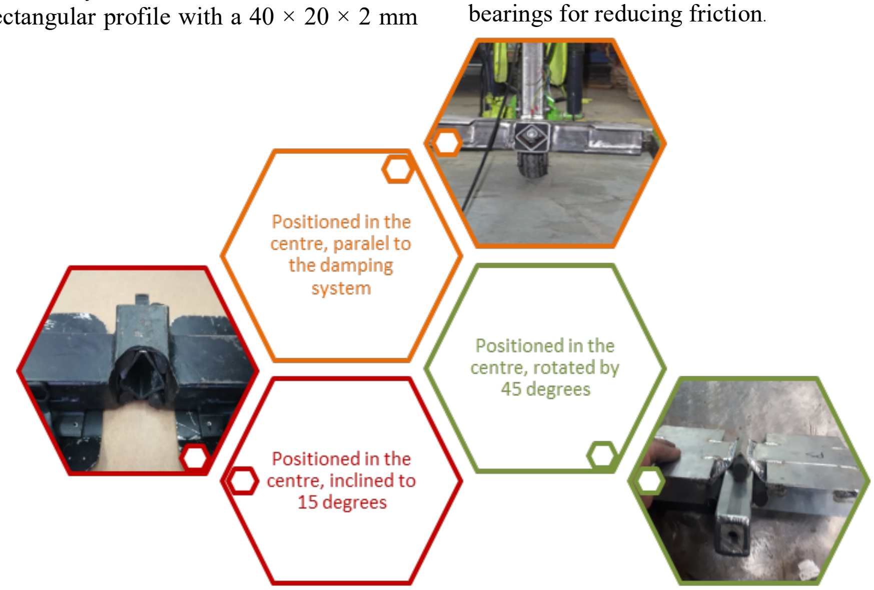


Fig. 10. The tilt system.

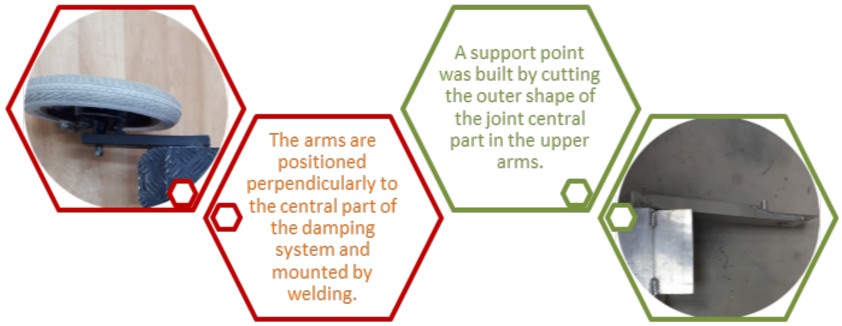


Fig. 11. Rear axle arms.

3.8 Elastic damping system

Nowadays there are several elastic damping systems, designed and used by several companies, having different shapes and solutions depending on the tasks that they have to bear and fulfil, as the case may be.

Such a system is also the RoSta System, being among the first identified. It was developed in the mid-1940s, being conceived by Rohr in the village of Staufen, hence the name of the system known today on a large scale.

The elements with elastic damping have multiple functions, having the role of torsion spring and support with anti-vibration pivot. Given that it has an operating angle of +/− 30 degrees, with different dimensions, it can have different varieties in the construction of a mechanism.

The Flexiride full-rubber system works by rubbing rather than compression, ensuring a more angular conformation, better cushioning effect and smoother rolling [7].

Torflex and RoSta systems use square profiles that have 4 rubber cylinders that support and react to the movements of another square profile [7].

In the case of suspension on the spring the period of oscillation is longer, regardless of whether only one of the wheels overcomes an obstacle. In the case of suspension in which a twisted shaft system is used, the oscillation period is smoother and shorter, since each wheel moves individually [7].

4. CONCLUSIONS

The purpose of this research was to develop an easy-to-use, yet robust, foldable electric tricycle capable of providing a comfortable driving experience on every type of road.

The main contributions consist of the design of the tricycle structure together with the folding mechanism, the development of a frame-specific suspension system using elastic damping elements and the measurement of tensile values in several key locations on the tricycle using manometers.

In order to achieve these, three physical prototypes where built and compared and further improvements were made based on the measurements realised during the research.

The main conclusion is that the stability of the bike could be greatly increased by using a ROSTA suspension / damping as a tilt mechanism [6]. As expected, from the kinematic analysis, the rubber-based suspension offered good vibration attenuation, making this vehicle sportier and more suitable for all types of terrain.

As for further research, because the behaviour of the friction-based suspension is nonlinear, the general behaviour can be improved by choosing an appropriate size of suspension based on an individual anthropological measurement.

In Table 1, the technical specifications of all three Greeny versions are presented.

All versions have the same configuration (3 12" wheels, 1F2R) but for the last version the frame material was changed in order to lower the tricycle weight (from 32 kg to 22 kg) which increases the autonomy and improves the ease of transport in folded position.

Also, the material change helps increasing the maximum speed of the tricycle from 20 km/h to 25 km/h which is the speed limit for this type of vehicle.

Greeny V3.0 brings an improvement regarding the batteries with implication in the autonomy and ecological part of our project.

Most torsion systems allow the manufacturer to adjust their damping capacity, so that they are neither too rigid nor too weak, a process that uses progressive torsion, considering the load that the respective vehicle bears. The time for charging decreased from 10 h (V1.0) to 2 h (V3.0).

The length of the tricycle was affected by the modification on the folding system and by the design of the rear axle. The height was increased in order to improve the ergonomics of the vehicle. The width of V2.0 and V3.0 is larger because more space was needed for the feet and to increase stability.

A driving motor of 250 W power is mounted on all versions.

REFERENCES

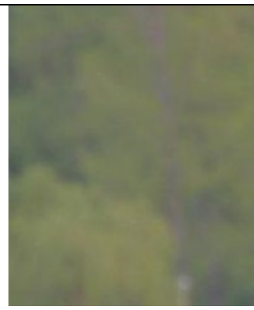
[1] C.C. Attribution, „electric vehicles news,” Available: https://www.electricvehiclesnews.com/History/historyearlyIII.htm.

[2] Acton, „actonglobal.com 2013. Available: https://www.actonglobal.com/products/m-scooter.

[3] Qugo, „qugo.nl,” 2016. Available: http://www.qugo.nl/nl/de-qugo.

Table 1

Greeny evolution

Features / Versions	 **V1.0**	 **V2.0**	 **V3.0**
Wheel configuration	1F2R	1F2R	1F2R
Tilt wheels	3	3	3
Framework	Steel	Steel	Aluminium
Maximum passenger weight	300 kg	300 kg	300 kg
Full speed	20 km/h	20 km/h	25 km/h
Autonomy	25 km	25 km	30 km
Battery	36 V, 14 mA lead acid	36 V, 10 mA lead acid	36 V, 10 mA lithium-ion
Charging time	10 ore	6 ore	2 ore
Weight	42 kg	32 kg	22 kg
Dimensions (L × W × H) mm	500 × 592 × 910 (folded)	530 × 660 × 760 (folded)	500 × 660 × 760 (folded)
	910 × 600 × 1130	920 × 660 × 1250	930 × 660 × 1250
Power of action	250 W	250 W	250 W
Wheel size	12"	12"	12"

[4] YikeBike, „yikebike.com. Available: http://www.yikebike.com/model-v/.
[5] C. Andone, „Stiinta si tehnica," *Greeny triciclu electric,* pp. 29-31, 12 January 2012.
[6] Rosta, „rosta.ch,". Available: https://www.rosta.ch/en/about-us/history/.
[7] heuniversalgroup, „theuniversalgroup.com," February 2018. Available: http://www.theuniversalgroup.com/w/wp-content/uploads/2018/03/P10-Flexiride-brochure.pdf.
[8] G. O.-G. ,. M.-G. Camilo Parra-Palacio, „Enfoque de industrialización de proyectos académicos – Un," *"Innovation in Engineering, Technology and Education for Competitiveness and Prosperity" August 14–16, 2013 Cancun, Mexico.,* 2013.
[9] M. Aga, A. Okada, Analysis of vehicle stability control effectiveness from accident data, ESV Conference, Nagoya (2003).