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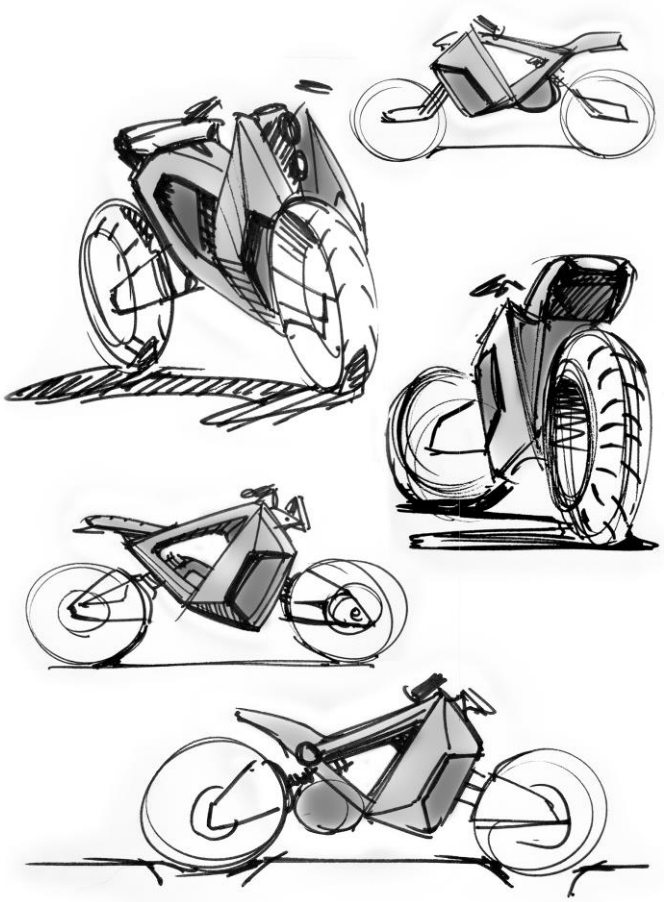
Motorcycle Design

Defining a new typology and form for the electric motorcycle of the 21st century.



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I hereby declare that the work submitted is mine and that where I have made use of another's work, I have attributed the source(s) according to the Regulations set in the Student's Handbook.

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Abstract

The following paper is a Thesis, written for the MSc in Strategic Product Design. The purpose of this project is to research the engineering and design identity of the electric motorcycle of the 21st century. As part of the project, a research has been conducted, regarding the history of motorcycles and engineering that shaped their current visual form. Following, in this paper, there has been presented the current technology in electric motorcycles with production models and brands that are investing in electric vehicles.

The main goal of this paper, is to present a design proposal for an electric motorcycle. Based on the engineering research on electric motors for electric vehicles, a reader will find a full description of the parts that assembly an electric motorcycle, the important points that need to be addressed while designing a concept for an electric motorcycle and the trade-offs that must be resolved regarding the geometry, ergonomics and performance.

At the final chapters, our concept electric motorcycle takes form with sketches and different variations. A final concept is being developed further and presented through Adobe Photoshop renders.

For completing this project, I would like to thank my supervisor, Professor Georgios Liamadis, as he trusted me with a project that exceeded the available time frame and guided me through this process with his experience in Automotive Design. I would also like to thank Mr. Errikos Ampatzoglou, for his tutoring in vehicle design sketching and rendering and his professional experience and advise in a concept design follow through pipe line.

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1 INTRODUCTION

Motorcycle Design is a little bit more complex process than Automotive Design. This is since a motorcycle, is all in one, the engine, the body, the exterior and the interior of a car, altogether combined into a single space. Thus, a motorcycle designer needs to obtain technical knowledge of motorcycle engineering to deliver a concept from an idea.

Moreover, motorcyclists, is a peculiar target group, with a technical knowledge higher than any other vehicle buyer. They need to know their motorcycle function, have a clear image of its parts and understand of their role. Most motorcyclists love engineering and they buy a motorcycle not from necessity but for passion.

When a motorcyclist is choosing his next motorcycle, he is considering details that are a lot more different from those when looking to buy a car. It is not irrelevant the fact that when a potential car buyer is looking a car, in which he is interested, firstly steps back to have a full image of the body and the shape but in the case of a potential motorcycle buyer, firstly he steps more close to see the details of the engine and the frame quality and then tends to have a more complete view.

In the new upcoming age of electric vehicles, motorcycles are tested as an archetype. Their shape has been always related to their engine and their form had the purpose of demonstrating their engineering superiority. Now days, with promotion of electric motor, motorcycle design need to reinvent its identity and test its potential from white paper conceptions.

2 Project Target

In this following project, our main target is to present a new form and typology for the electric motorcycle of the 21st century. The product of our research, will be a design solution for an electric motorcycle, which will appeal to traditional motorists who are looking to satisfy their passion for motorcycles through a new type of transportation, which is electric vehicles.

To be able to succeed in our target, we need to:

- understand the engineering behind the current internal combustion engine (ICE) motorcycles
- describe the engineering limitations that formed the design language of ICE motorcycles
- point out those characteristics, of ICE motorcycles that define their identity and have been imprinted in the minds of the motorists
- search which engineering limitations, connected with form and typology, exist on electric motorcycles and compare them with ICE motorcycles
- search possibilities for new forms of electric motorcycles and suggest variations.

3 Target Group

In motorcycle history, there was always a stereotype of the motorcycle motorist. “He” and less frequently “she”, was the rebellious man of his generation, looking for adventure and speed. Setting out to the unknown with only companion his motorcycle.

Connected with outlaw groups, motorcycles had always a bad reputation, fed also by the dangers of driving a motorcycle. Not an everyday type would choose a motorcycle as a mean of transportation and most of them who choose them were looking something more than just a means of moving around.

All the above of course apply in the western world, Europe and north America where motorcycles were developed in the world of racing and motor clubs. In the east, the case was far more different.

Motorcycles in Asia were traditionally just a transportation vehicle, cheap, easy to maintain and easy to maneuver through traffic. It is not by accident that most of the small, urban motorcycles, like scooters, have been developed in those countries and eventually passed to other places of the world.

Nowadays, medium and high performance motorcycles are driven by people that ten years ago would not choose this kind of transportation. Motorcycles, offering high traffic advantages in modern cities, along with their low function cost, the development of safety clothing and accessories and the improvement of driving culture towards motorcycles, have been driven by an expanded target group.

For this specific project, our target group will be defined by a more traditional motorist persona as our purpose is to define the typology of the electric motorcycle based on emotional choices and not so much as logical ones. As D. Norman noted, “our consumer choices are based on thymic and defined by emotion, rather than logic, which follows as documentation of a choice that has preceded”, and in this project, emotion for motorcycles is the more important factor we wish to cover.

Our target group are:

- experienced motorcycle riders
- new motorists, with no riding experience, that want to get into the motorcycle world and see, in electric motorcycles, a safe and exciting chance to do so
- between the age of 18 and 60
- male or female
- living in a European city

They have:

- in case off motorcycle riders, experience in riding ICE motorcycles
- passion for motorcycle engineering
- interest in classic motorcycles and racing
- interest in electric vehicles

They are looking for:

- a mean of transportation in urban environment

- a mean of transportation for leisure traveling on road (instead of leisure activities off road)
- a motorcycle that will excite them from engineering and performance point of view
- a motorcycle that will match their aesthetics needs
- a new alternative, environment friendly vehicle

Our target group, is a varied group of people having mostly a common factor, love for motorcycles and the vision for electrifying all vehicles.

4 MOTORCYCLE HISTORY

Originally, the first motorcycle was nothing more than just a bicycle, mounted with a motor, thus its first name was “motor bicycle”. The term “motorcycle” was a trademark name with which Werner presented his concept in the Parisian exhibition. Since then the term motorcycle was used so often for this type of vehicles that the exclusive use of the term was not possible anymore and so motorcycle was recognized as a public domain.

As “motorcycle”, is described any motorized vehicle, that has two in line wheels. Its stability in motion is based on the conservation of angular momentum principle.

The first motorcycle was invented by a French engineer named Louis Guillaume Perreaux. Perreaux patented his invention on 16 March 1869. His motorcycle, Vélocipede à Grande Vitesse (fig. 4.1), was motorized with a steam motor.

Figure 4.1: Louis-Guillaume Perreaux, Vélocipède, 1868. (Musée de l'Ile-de-France, O. Ravoire).

The first internal combustion engine motorcycle was built by two well-known German inventors, Gottlieb Daimler and Wilhelm Maybach in 1885 (fig. 4.2). The two inventors are also responsible for the construction of the first car.

Figure 4.2: Daimler’s internal combustion engine motorcycle (Mercedes-Benz Museum, Stuttgart, D. Maioglou).

The first production motorcycles came from Hildebrand & Wolfmüller and they had a steam engine until they partnered up with Alois Wolfmüller and produced a two cylinder, four-stroke engine in 1894 (fig. 4.3).

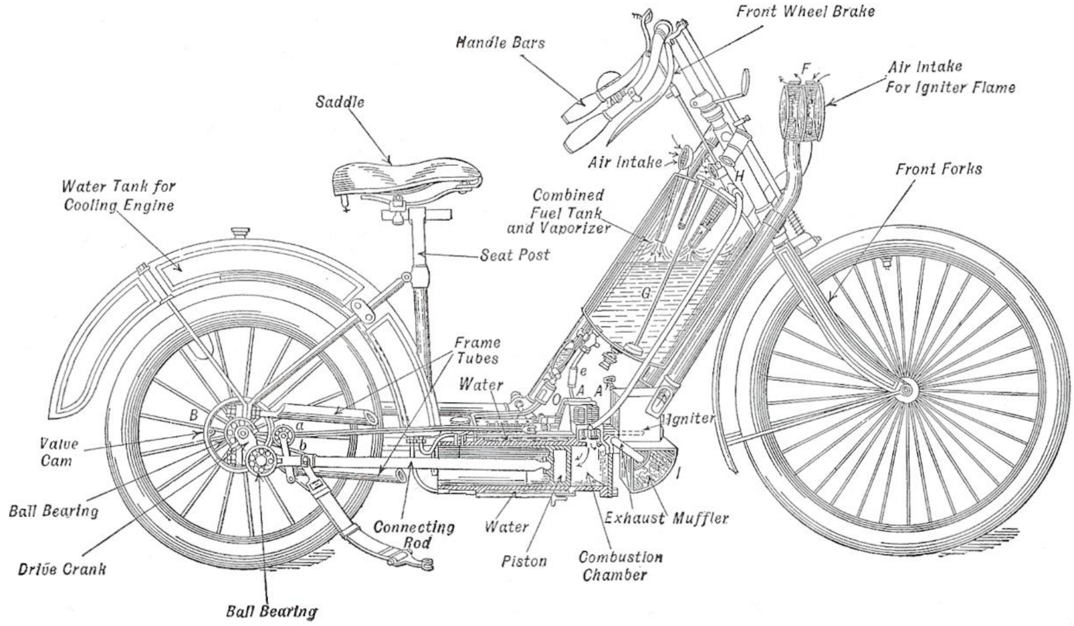


Figure 4.3: Diagram of 1894 Hildebrand & Wolfmüller (Victor Wilfred Pagé, Early Motorcycles: Construction).

Since the first motorcycles, which where nothing more than more complicated bicycles with engines, motorcycle engineering witnessed a continuous evolution, with companies experimenting and delivering new designs in Europe and USA. Till 60's, the main motorcycle producers where in USA, UK, Germany and Italy and this is when Japanese Industries made their big introduction to motorcycle world with game changing designs.

4.1 Types of Motorcycles

There are different types of motorcycles, depending mostly on the use of the vehicle. This factor affects the geometry of the vehicle, engine specification, riding posture and target group.

- **Naked**

In this category are included motorcycles lacking almost completely aerodynamic protectors and fairings. Mostly driven in urban environments, the lack of extra parts make them more light, easy to maneuver and with less damage in case of small accidents. Mostly known for an aggressive style (fig. 4.4).

- **Touring and Grand Touring**

Made for riding and traveling and every weather condition, mostly with high capacity engines, and equipped with everything that can make a trip comfortable, including aerodynamic protectors, suitcases, windshields, ergonomic seats and touring suspension (fig. 4.5).

Figure 4.4: Kawasaki-z 800

Figure 4.5: BMW K 1600 GTL Touring

Race Replica (Supersport)

Performance motorcycles based on current racing bikes with specification derived directly from racing world and supersport championship. Modified for public road use, equipped with full body fairings, massive power engines and sport suspension. Mostly driven for excitement and adrenaline (fig. 4.6).

Cruiser

Cruiser motorcycles owe their origin from USA. Their name reveilles their use which is mostly for cruising highways in relaxing speeds. Mounted with high cubic capacity v-twin engines of high torque but low in horsepower, mostly known for their reliability, distinctive sound and abysmal fuel consumption. Also, known as Custom motorcycles as they offer grate flexibility in personal customization with aftermarket parts (fig. 4.7).

Figure 4.6: MV Agusta F3 675

Figure 4.7: Harley Davidson Cruiser Motorcycle.

Cross (off-road)

Models designed based mostly on motocross races. Specifically designed for off-road rides with high speeds and jumps offering excitement and fun. Equipped with low dive suspension, big front wheels for easy obstacle overcoming and small and middle sized two stroke and four stroke engines (fig. 4.8).

Enduro

Like Cross motorcycles, but aimed for riding in open trails, passing through forests, over streams, climbing hills for long distances and not in circuits as the cross motorcycles. Enduro is an endurance test between the rider and the terrain testing the rider physically and mentally. Equipped for long distances with bigger tangs than Cross bikes and middle sized engines (fig. 4.9).

Figure 4.8: Cross-Dirt, KTM 500 EXC

Figure 4.9: Enduro, Suzuki DR-Z400S

On-Off

Motorcycles that drive through all types of terrain, from asphalt to dirt roads. Based on endure bikes but with alterations to be more comfortable and stable in high-way roads. Bigger fuel tanks, shorter suspension, better wind protection and higher cubic capacity engines for everyday use and long distance travel (fig. 4.10).

Trial

Trial motorcycles are restricted in contests and are not road motorcycles. Trial motorcycles depend on their lightness and agility to overcome any obstacle. They have small engines, no seats and the riding style is very particular for balance and maneuverability in small spaces (fig. 4.11).

Figure 4.10: On-Off, Honda Transalp

Figure 4.11: Trial motorcycle

Chopper

Chopper as term comes from the word “chop” meaning “cutting down”. Chopper motorcycles where named after the extreme customization their ridders performed on them. Born in USA with admirers all over the world accompanied by lifestyle of freedom, rebellion, outlaw life and independence. Long front suspensions, chrome hand-made parts, air spray painting, free style exhaust systems and leather are their main characteristics (fig. 4.12).

Café Racer

Born in UK by British weekend motorists who used to race between villages from one Café to another. Customized motorcycles for street racing with aftermarket, mostly hand-made fairings and parts, on steering axes fitted short bars gave the chance to youngsters of 60’s to feel the rush of illegal racing. Nowadays, they are part of a Vintage movement that comes again to surface with most of OEMs releasing model based on them (fig. 4.13).

Figure 4.12: Chopper Motorcycle (inspired by the movie “Easy Rider”).

Figure 4.13: Adam Grice’s Triton with a 744 cc Triumph T140V engine from the mid Seventies

Scrambler

One of the first attempts of having a motorcycle built for riding in all terrains. Dirt tyres, small fuel tanks, seats that permit different riding styles, large wheel fenders for dirt protection. Ideal bike for a surfer that wants to park his bike on the beach (fig. 4.14).

Rally/Raid

Born from experience gained in African competitions of Dakar Rally, with common characteristics from enduro models (fig. 4.15).

Motard

Racing in competitions called Supermotard with technical characteristics of dirt bikes with smaller wheels customized for asphalt racing (fig. 4.16).

Figure 4.14: BMW Scrambler

Figure 4.15: KTM 450 Dacar

Figure 4.16: Aprilia SXV Motard

Sport-Touring

Motorcycles designed for touring in high speeds. Full body fairings, high performance engines and riding position between a racing bike and a touring are made for long distance travels in fast speeds (fig. 4.17).

Figure 4.17: Hond VFR 1200 Sport Touring

5 Current Trends & Aesthetics

Motorcycles are, for some riders, a mean of externalizing their aesthetics and culture. You buy a motorcycle not only because it is quick and moves easily in traffic, but also because it looks cool, it makes you stand out from the rest and it is aggressive.

The design identity off your motorcycle is the way to express yourself. You use it to make a stand. It is a product that relates to “image” and such a product, its shape is formed by the current cultural, artistic, technological and political trends.

Technology has changed enormously the last ten years. It is not just a necessity any more but it is our environment, it is our life. Everything is connected in the new era of internet of things and all around us is a part of an intelligent network that is there to make our life easier, using the least possible resources, either those are money or energy.

A current motorcycle rider expects from his motorcycle to be part of this network and not only an independent piece of machinery. It demands from his vehicle to be safe but also fun, to be made by new “intelligent” materials but at the same time to have a low price and maintenance cost. He wants to buy a brand, with history and purpose, that will make him part of their culture.

On the other hand, there is a recent turn to the old times. We are turning our view to music of the past, trying to recognize those ingredients that made music of the last decades to be genuine. In a world of mass production products, people are looking for handmade artifacts that have a back story. Appreciate materials that connect them with the earth, like stone and wood and leather.

Motorcycles are part of that nostalgia. Restoration projects are flourishing. Old parts are used in new models. Vintage is everywhere and riders customize their motorcycles to stand out. That, which was once part of chopper riders, customized motorcycle parts are now obvious to any type of motorcycle coming into production.

Riders expect from their motorcycles to have high end technology but at the same time give them the ability to customize according to their wants, needs and aesthetics. International brands like Yamaha and BMW offering models with customized, limited production extras and model versions that are fully adaptable to their personal style and identity. This is the reason they form partnerships with small customization workshops and design studios that have their own identity and followers.

Yamaha has launched a strategy through which seeks out *“talented bike customizers to provide inspirational ideas on how to transform modern Yamaha models into what they have entitled ‘Yard Built specials*” (fig. 5.1). They further give the opportunity to those customizers to develop and produce unique aftermarket kits and sell them to Yamaha owners who want to customize their brand-new motorcycle.

Vintage, retro, café racers, scramblers are words mentioned on their latest model releases. They search for “genuine” and riders want to be part of the development process. The form of their motorcycle is based on old, classic models but the technology underneath is high end.

Figure 5.1: Yamaha Yard Built XJR1300 'Monkeefist' by Wrenchmonkees (yamaha-motor.eu)

BMW with R Nine T model (fig. 5.2), responds to this demand by developing a motorcycle with Café Racer design identity and offering, in factory, customization kits. It is one of the most advanced motorcycles but its look is either futuristic nor screams high end technology. It is a tribute to BMW's motorcycle history, with design lines from early 20th century and colors of tradition.

Figure 5.2: BMW R nine T (bmw-motorrad.com)

This need for customization has given rise to small motorcycle workshops, that have now created their own brand, with defined design language, partners of global motorcycle brands. Roland Sands Design (fig. 5.3) indicate in their imprint: "*Roland Sands Design is a motorcycle, product and apparel company that has its roots in racing, custom bike building and design. Our inspiration comes from a high-performance background that blends the love of two wheels with the desire to create unique products. We live the two-wheeled life and our crew is a*

Figure 5.3: Ola Stenegard, Head of BMW Motorrad Design, and Roland Sands with their BMW Concept 90 (formtrends.com)

diverse collection of road racers, off-road, dirt track, supermoto and custom bike builders and riders. It's this diversity that allows us to work with the best in the industry on a variety of projects". This is how one speaks directly to the heart of the riders now days and this is the reason why they were selected to be part of a BMW concept 90 project based on BMW R90 S of 1973 (fig. 5.4).

Figure 5.4: BMW R90 S 1973 (formtrends.com)

6 ELECTRIC MOTORCYCLES

Current motorcycles and their design is part of a long history of engineering, racing, testing and experimenting around internal combustion engines. The engine is the heart of any vehicle but for motorcycles, the engine is more than that.

In some models the engine is part of the chassis, it connects and brings all the parts together in a complete body. The geometry, dimensions, use, riding style, are all based on the engine and most motorcycles where built having their engine as fixed from the conception step.

It is logically delivered then that the form of the motorcycles is connected to their engine and thus combustion engine as it is the most globally used engine. If we change the type of engine we are using to power our vehicle that means also that we can change our geometry.

Naturally though most of the latest electric motorcycles are not different from their internal combustion predecessors. There are many reasons why this is happening.

First of all, motorcycles are products produced for a market and thus they must obey to laws of profit. Designing and producing a vehicle from white paper cost a lot of time and money. Factories and production machines are already there and well-known brands must use them as it is their investment. They cannot change all their production line for few electric models. Which takes us to the second reason for why electric motorcycles have a traditional look.

Electric motorcycles are not monopoly in the motorcycle market. Only a few percentage of the new registered motorcycles every year are electric. Big sellers are still petrol based models and big OEMs have still to produce them in large numbers to be profitable. This means that most of the motorcycle parts, like chassis, suspensions, wheels, drives are already there and they must use them and so, most of the newly produced electric models are based on conventional ones with just few modifications so they can fit an electric motor and its necessary accompanied parts.

Furthermore, motorists love the look of their motorcycle. They are more traditional, skeptical, engineering oriented, old-fashioned petrol heads which tend to stick to history and modify their bikes so they can be heard from miles. Introducing a new image of a motorcycle, electric, silent, clean, with new typology, new geometry and even a completely new form is a high marketing risk. That is the reason why the petrol tank is still there, covering the batteries although it has no use in an electric bike and something else could be at its place or even nothing at all. Riders spend lots of money to paint the petrol tank and make their motorcycle stand out. You need to give to the riders something else to cover that need before you make that change and this the same situation with all the motorcycle parts.

Electric motorcycles must reinvent themselves, redefine their character and this will take time. It is not a transition that can happen over a night. The use of existing conventional motorcycle designs is unavoidable and that is not entirely a bad thing as we are creatures of habit and we like familiar shapes and forms. But having an entirely new heart in our vehicles means that we have new endless possibilities that we should explore.

6.1 History of Electric Motorcycles

Early 1900s

As it was happening with all types of energy at that time, like steam and petrol engines, electric engines mounted on bicycles was a fact from 1895 with many inventors presenting their drawings for patents (fig. 6.1). Unfortunately, internal combustion engines where evolving faster in terms of power, range and reliability and overshadowed electric motors.

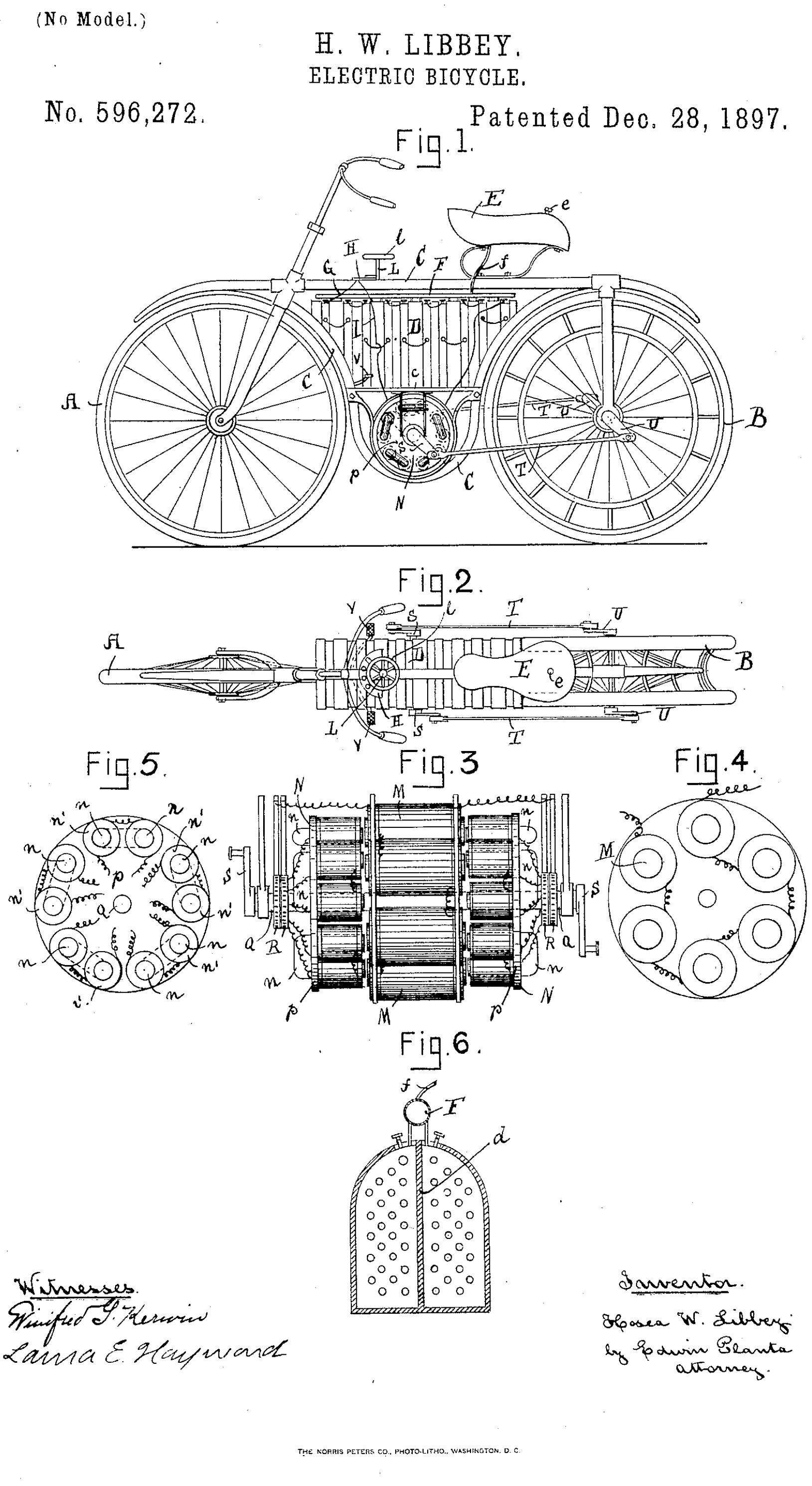


Figure 6.1: H. W. Libbey Electric Bicycle. Patented 28 Dec 1897 (United States EEICE)

The Early 1940s

Before and during WWII, due to fuel rationing, few motorcycle companies produced electric bicycles such as the Limelette brothers that existed before war in Brussels and Merle Williams of Long Beach, California who invented a two-wheeled electric motorcycle that towed a single wheeled trailer.

1950–1980

In 1967 Karl Kordesch introduced a hybrid electric motorcycle with a range of 320 km per gallon and a speed of 40km/h. In the same year, Indian Motorcycles presented their electric motorcycle called Papoose. In the early 1970s, Mike Corbin built a street-legal commuter electric motorcycle called the Corbin Electric. Later in 1974, Corbin, riding a motorcycle called the Quick Silver (fig. 6.2), set the electric motorcycle speed world record at 266.165 km/h.

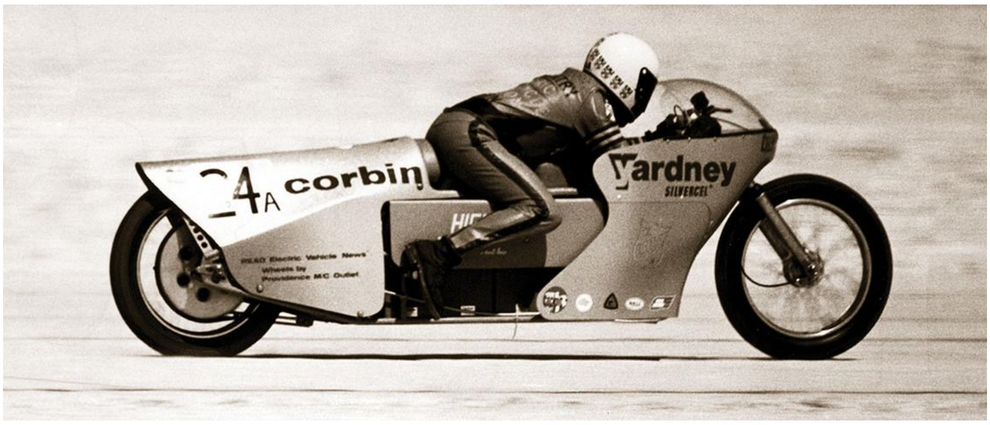


Figure 6.2: Mike Corbin, Quicksilver Electric Speed Record Motorcycle (Corbin Motors).

1980–2000

In 1988, Ed Rannberg, founder of Eyeball Engineering, tested his electric drag motorcycle in Bonneville. In 1995, Electric Motorbike Inc. was founded by Scott Cronk and Rick Whisman in Santa Rosa, California. In 1996, Peugeot released the first mass produced electric scooter called Scoot'Elec (fig. 6.3) with a range of a range of 40 km.

Figure 6.3: Peugeot Scoot'Elec 1996

2000 to present

On 10 November 2007 Killacycle established a drag racing record of 7.824 seconds at 270 km/h in Phoenix, Arizona at the All Harley Drag Racing Association (AHDRA) 2007. On 4–5 April 2009, Zero Motorcycles hosted the first all-electric off-road endurance race called "24 Hours of Electricross" in San Jose. On 14 June 2009, the first electric Time Trial Xtreme Grand Prix (TTXGP) took place on the Isle of Man. On 30 August 2011, Chip Yates riding his prototype electric superbike (fig. 6.4) established an official Guinness record of the fastest electric motorcycle with a speed of 316.899 km/h at Bonneville. On 30 June 2013, Carlin Dunne with a Lightning Motorcycle beat conventional motorcycles at Pikes Peak. Today there are a lot of new companies introducing new models of electric motorcycles in the market.

Figure 6.4: Chip Yates riding his prototype electric superbike

6.2 EXISTING PRODUCTION MODELS

Today there are a lot of small startup companies with electric production models supported by electric research institutes as well as well established brands who make their firsts steps in electric motorcycles by introducing few concepts. Furthermore, there are many independent engineering teams and workshops who have launched their own projects of handmade models.

In this chapter, we will present the most successful ones based on market appeal and also the most technologically advanced although some production companies have failed by economically standards.

6.2.1 Zero Motorcycles

Zero Motorcycles Inc. started in 2006 by a former NASA engineer, Neal Saiki. It is an American Manufacturer only of electric motorcycles firstly based in Santa Cruz California. For 2017 they have launched six models, Zero S, Zero SR, Zero DS, Zero DSR, Zero FX, Zero FXS. Although they lack imagination in giving names for their models, their engine technology is of high standards.

Zero Motorcycles uses an electric brushless motor named, Z-Force®, which was developed and produced in house. The motor features an interior permanent magnet that requires no liquid or forced-air cooling and no routine maintenance. The motor is Capable of as much as 70 hp and 116 ft-lbs of torque (Zeromotorcycles).

Their battery pack is also developed in house. They use lithium-ion cell chemistry and advanced battery management systems that requires also no active cooling or routine maintenance.

Regarding range at present, the longest range in the lineup goes to the Zero S and Zero SR ZF13.0 + Power Tank with 202 miles in the city.

Zero Motorcycles produce street motorcycles like the Zero S (fig. 6.5) Line with features of naked bike and Zero FX line with feature of endure bikes for more off road rides.

Figure 6.5: Zero S and Zero FXS , Zero Motorcycles (zero com)

6.2.2 Victory Motorcycles - Empulse® TT

Victory Motorcycles is an American motorcycle manufacturer since 1998 with its production facilities at Iowa US. Although Victory's motorcycles are designed to compete directly with Harley-Davidson and similar American-style motorcycle brands, with V-twin engines and touring, sport-touring, and cruiser configurations, in 2015 they bought Brammo Motorcycles an Oregon-based electric motorcycle manufacturer which in 2010 announced the Empulse electric motorcycle.

For 2016, Victory Motorcycle launched under their banner the Empulse® TT (fig. 6.6). The bike has a Liquid cooled, permanent magnet, AC electric motor with regenerative braking. Its battery pack is a Power Lithium Ion by Brammo.

Of great importance is the fact that this electric motorcycle has a 6-speed gearbox, although other electric motorcycles companies have chosen to not use one as it is not needed in an electric motorcycle. The use of gearbox adds extra weight, complexity and need of maintenance to the motorcycle. Nonetheless it creates a feeling of traditional motorcycle engine and that is an advantage they wanted to keep for the riding experience.

Figure 6.6: 2016 Victory Motorcycles EMPULSE TT

6.2.3 Energica Motor Company S.p.A.

Energica Motor Company is an Italian super-sport electric motorcycles manufacturer. Its headquarters are placed in Modena, Italy. They produce three versions of Energica, the Energica Eva, a naked motorcycle and two super-sport versions, the Energica Ego and Energica Ego 45 (fig. 6.7). The Energica has racing blood as it comes from the eCRP 1.4, the runner-up World Champion and European Champion electric racing motorcycle.

Energica has a Permanent Magnet AC motor delivering a power of 100 kW (about 136hp). Its battery pack will give you a range of 150 KM in speed of 80 km/h. Energica does not have a gearbox or a clutch. The Ego is the fastest production electric motorcycle with the highest top speed (150 mph) and it has the fastest acceleration (0-to-60-mph in about 3 seconds).

Figure 6.7: Energica Ego 45 (Energica Motor Company)

6.2.4 Lightning Motorcycle Corp

Lighting motorcycle is a record winner racing motorcycle manufactured in California USA. Since the foundation of the company in 2006 by Richard Hatfield, they have broken two land speed records on the Bonneville Salt Flats, the latest in 2012 with a top speed of 352.32 km/h. In 2013 Rider Carlin Dunne and Lightning's LS-218 Superbike won the motorcycle field at Pikes Peak, making it the first electric bike to beat out all its conventional internal combustion engine rivals.

Lightning LS-218 (fig. 6.8) is mounted with a IPM liquid cooled 150kw+ 10,500 rpm electric motor that delivers 200hp with a direct drive without the use of transmission. The battery pack gives an average range of 200-250km per charge, depending the speed.

Lightning Motorcycles have not yet delivered a production model although they are in process of getting reservations. The first delivery is expected to take place this year.

Figure 6.8: Lightning LS-218 (Lightning Motorcycle Corp)

6.2.5 Alta Motors

Alta Motors is an American motorcycle manufacturer that managed this year, after research, design, prototyping, re-designing and testing, to produce this year two models, the Redshift MX and Redshift SM (fig. 6.9).

Figure 6.9: Redshift MX and Redshift SM (Alta Motors)

Redshift MX is a motocross bike and Redshift SM is a super-motard bike. They both have a Permanent Magnet AC motor delivering 40hp. Their battery packs are waterproof Li-Ion 350v. No transmission is used.

6.2.6 Mission Motorcycles

Figure 6.10: Mission R (Mission Motors)

Mission Motors was an innovative electric superbike startup company based in California USA. Mission Motors were scheduled to produce two versions, the Mission R and Mission RS. By technological standards Mission bikes were far from any other electric motorcycle at this time, produced or concept. They were pushing the boundaries of what electric motorcycles could do and would have had a major impact on the motorcycle industry generally and not only in electric motorcycles.

Their motors were 100 kW liquid-cooled 3-phase AC-Induction motors and 14kwh batteries (fig. 6.11). Mission R was developed by competing in races such as Isle of Man in 2009, succeeding the 4th place in the PRO class and setting the AMA electric motorcycle land speed record during the BUB Motorcycle Speed Trials at the Bonneville Salt Flats in the same year.

Until 2014, all things seemed promising with Mission Motors when in 2015 the rumors for filing for bankruptcy were confirmed leaving behind unanswered questions and even bigger void in electric motorcycle history.

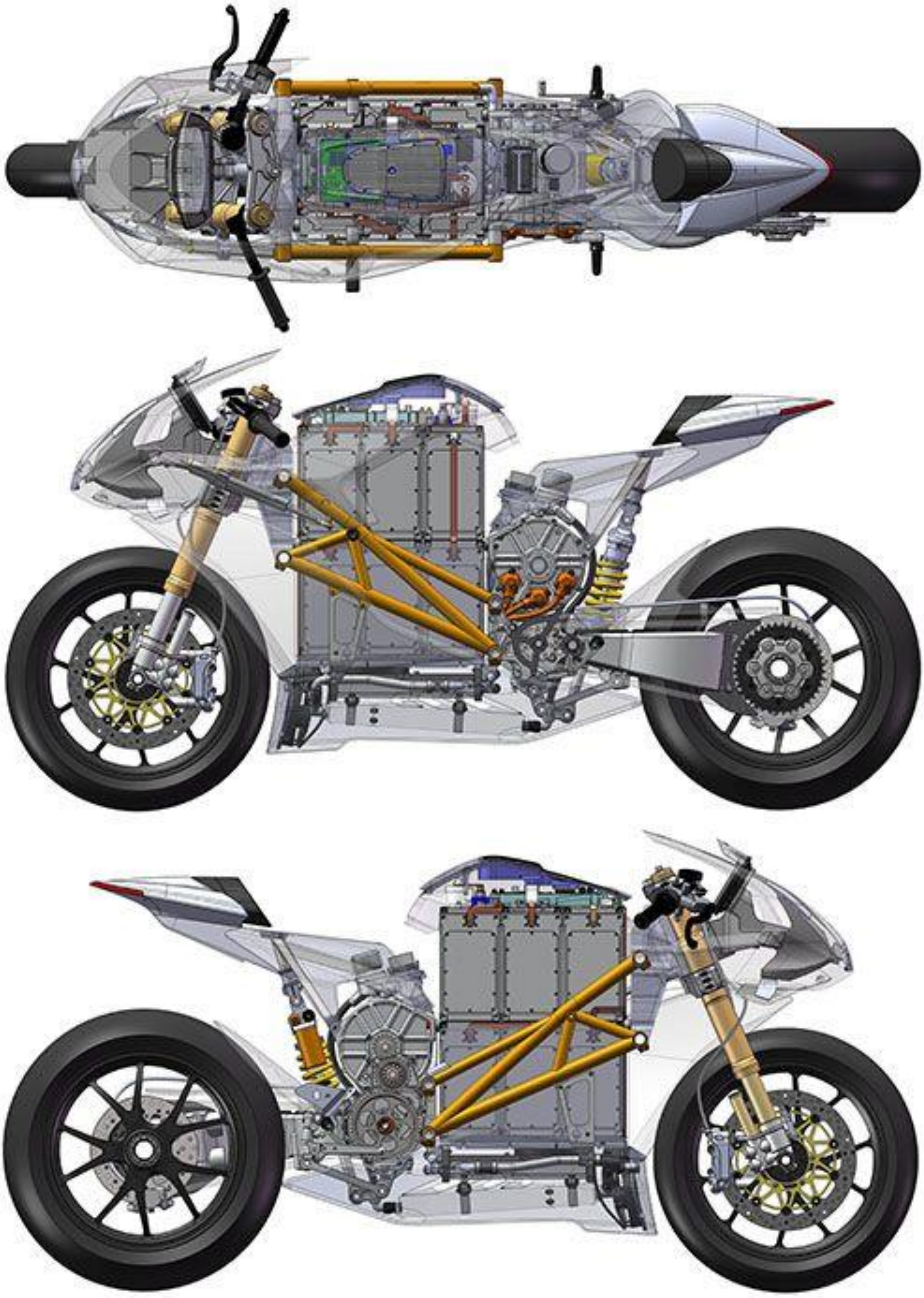


Figure 6.11: Mission R layout (Mission Motors)

6.2.7 KTM-Freeride E

KTM, the Austrian motorcycle manufacturer, have produced in small numbers, the Freeride E electric motorcycle. It is a motocross bike with a brushless permanent magnet synchronous electric motor that delivers 16 kW. The power pack is consisted of 360 lithium ion battery cells. All three versions have no transmission gears giving power with a direct drive to the rear wheel. The versions are KTM Freeride E-XC, E-SX and E-SM which is an enduro bike modified for street use.

Figure 6.12: KTM Freeride E-SM (KTM)

6.2.8 BMW-Motorrad

The well know German motorcycle manufacturer BMW, with long history in motorcycle design and innovation since its foundation last century, has got into the E-Game with C-Evolution.

This E-Scooter (fig. 6.13) is the answer of BMW to the increasing demand for Urban E-mobility. The engine is a permanently excited synchronous motor with surface magnets delivering 48 hp. Featuring a new generation of batteries with a cell capacity of 94 Ah, as used in the current BMW i3 and drive train swing arm with toothed belt and ring gear transmission to the rear axle.

Figure 6.13: BMW C-Evolution (BMW Motorrad)

Furthermore, BMW Motorrad had announced the experimental vehicle eRR (fig.6.14) created as a project with the Technical University of Munich. Regarding design and chassis technology the eRR is based on BMW S 1000 RR, however using an all-electric drive.

Figure 6.14: BMW eRR (BMW Motorrad)

So far, we have seen models that are based on conventional motorcycles, mostly focused in electric vehicle technology performance research and less on design innovation. There are some attempts for design experimentation that have succeeded their goals, introducing at the same time high end E-technology.

6.2.9 Yamaha-PES2/PED2

At the 2015 Tokyo Motor Show, Yamaha showed the latest version of their PES2 (Passion Electric Street) (fig. 6.15) and PED2 (Passion Electric Dirt) motorcycles. The PES2 is a street-sport model powered by a DC brushless motor with a lithium-ion battery. Yamaha have gone one step further by adding an electric motor built into the hub of the front wheel making PES2 into a two-wheel-drive motorcycle.

Figure 6.15: Yamaha-PES2 (Yamaha)

It is obvious that Yamaha has experimented with the design of the PES2 and took advantage of the new opportunities created by the lack of a massive internal combustion engine. Simple elegant design but at the same time living the motor open for the eye to see. Combining new material technology with electric engineering sophistication and light design. According to Yamaha, “PES2 is designed to have an operational feel that will seem natural, even to today’s motorcycle enthusiasts”, a point made by the presence of a sense of fuel tank line with a completely different use this time (fig. 6.16).

Figure 6.16: Yamaha-PES2 (Yamaha)

6.2.10 Harley-Davidson-LiveWire™

Harley Davidson entered dynamically the E-Game by launching a U.S. test ride tour in 2014 with 40 LiveWire electric motorcycle concepts (fig. 6.17). The motorcycle is not yet available to the market and expected to be not until 2020. The bike was featured in the Avengers:Age of Ultron movie and based on reviews so far, lacks the power of other electric bikes already on the market. Nonetheless the market has high hopes from HD and awaits its release.

Figure 6.17: HD LiveWire™ (Harley-Davidson)

6.2.11 Johammer

Figure 6.18: Johammer J1 (Johammer)

Johammer developed and manufactured in Austria the Johammer J1, a electric cruiser (fig. 6.18). In Johammer they searched from scratch to find the best solution and came with a design that offers many advantages. The chassis is far from conventional and electric motor and controller are integrated into the rear wheel.

Figure 6.19: Johammer J1 chassis motor and battery pack (Johammer)

The hub-center steering system with Twin-arm box-section front fork and progressive suspension along with the low center of gravity adds stability to the motorcycle (fig. 6.19). Powered by DC-excited synchronous motor with single-stage transmission and in house produced Li-ion battery.

Although the looks of the motorcycle may not appeal to all riders it is a production model that is based on creativity. As we will see later in the paper, the engineering that J1 is based on, exists since the beginning of motorcycles, nonetheless they selected not just to simply plant an electric motor into a conventional motorcycle concept but to resurface some ideas from the paste and combine it with new technology giving a retro style.

6.2.12 Saietta Group

Saietta Group comprises three interdependent divisions: Saietta Engineering, Saietta Racing and Saietta Motorcycles, based in UK. Saietta Motorcycles design from clean sheet and build from ground up, not using conventional methods of assembling parts from external suppliers.

For now, they develop one concept high performance electric motorcycle with elements of street fighter, named NGS (Next Generation Saietta). In the concept development, they incorporate new technologies such as, 3D Printing, Structural Monocoque and of course a new electric motor and battery technology.

The motorcycle is still under development with the first 100 bikes delivered before the end of 2017 as limited edition.

Figure 6.20: Saietta NGS (Saietta Motorcycles)

6.2.13 LITO Green Motion

Lito Sora is a Luxury Electric Superbike produced in Canada (fig. 6.21). The bike is powered by a liquid-cooled 3-phase AC induction motor with lithium-polymer battery pack. Their purpose is to offer luxury and performance to their riders.

Figure 6.21: Lito Sora (Sora Electric Superbike)

There is a wide list of electric motorcycle manufacturers all over the world. China is a lead manufacturer now in terms of numbers produced electric motorcycles per year. Although that maybe the case, a large percentage of motorcycles produced in China are scooters with low performance and range motors and this is the reason we excluded them from this chapter.

Our goal is to present to you innovative, lead models that will appeal to the average petrolhead traditional motorist who is interested in riding a high-performance machine, that gives him style and individuality. Naturally, practicality, comfort and efficiency are welcomed but as we have seen with our target group, those are not always deal breakers.

7 ELECTRIC MOTORCYCLE TECHNOLOGY & MECHANICS

In the following chapter, we will present the basic engineering components of an electric motorcycle and how interact with each other.

7.1 DRIVE SYSTEMS

Drive systems transfer motion from the engine to the wheels. The speed of the vehicle depends on the output of the engine. Engine torque or engine power (hp/kw) are used to measure engine's output. Torque is measured in lbf-in, ft-lb, or N-m and motor speed is measured in rpm.

An internal combustion engine, or even an electric motor, rotates at specific speed and torque. The rotation of the engine is transmitted through gearing to the wheel axle. The transmission gearing changes the speed of the rotation to a slower speed. Engine speed and engine torque are inversely proportional. The slower the output speed, the higher the output torque.

In a nutshell, the role of the drive system is to:

- Convert torque and engine speed to wheel motion
- Enable vehicle motion in different directions, back and forward
- Maximize fuel economy

Every component of the drive system has a specific function. The engine provides the raw power. The clutch, if exists (not in automatic transmission), interrupts the motion from the engine so that transmission gears can be shifted. Chain or belt drive, passes the motion from the engine and gearbox to the wheel. In many vehicles, instead of drive chain or belt, they use drive shaft.

Drive systems in electric motorcycles can be simpler than those of an internal combustion engine. An electric engine can deliver instant torque, once it has started. That means that it can function with one gear without the need of a complex gearbox. Although not having a gearbox is an advantage in terms of complexity, efficiency, maintenance and weight, few electric motorcycle manufactures prefer to use gearboxes as it contains the sense of a traditional motorcycle experience that many drivers seek, even to electric motors.

The differences between IC engines and electric engines power systems are listed below.

Table 7.1: Comparison of power systems (Lin 1999)

Internal combustion system	Electric battery system
Engine including cylinders, air intake	Battery
Fuel tank, carburetor, air filter	Electric motor(s)
Pump for lubricating oil, oil tank	Motor controller
Exhaust system	Transmission and chain
Transmission and chain	
Starter battery	

7.2 ELECTRIC MOTORS

Electric motors are not a new technology. There are many devices that we use every day that are based on electric motors. Home appliances, construction tools, toys and anything that uses motion as a function and electricity as power source.

The reason why electric motors are widely spread is reliability. Electric motors are simple in conception and production. Regardless of the size and function they are two basic components, the rotor (moving part) and the stator (the stationary part). Depending on their use there are naturally other parts (fig. 7.1).

Figure 7.1: Audi Q7 e-tron 2.0 TFSI Quattro Electric Motor (Audi.de)

Electric motors are based on the principle that a wire carrying electric current inside a magnetic field will experience rotating force. The magnetic field can be created by a permanent on an electric magnet. The stator is stationary and produces the magnetic flux, while the rotating armature or rotor contains the coils that carry the armature current. To increase motor speed, you increase armature voltage and to increase torque you increase the current flowing through the armature.

In an internal combustion engine (IC engine) the fuel bursts produce rotation with a fixed velocity-torque relation. In an electric motor, in the other hand, the ratio between torque and speed can be controlled independently and electronically within the controller. For example, in a pulse-width-modulated system the frequency of rotation of the magnetic field governs the speed output, while the phase difference between the rotor and stator fields determines torque (Vogel 2009).

Due to the independent control of speed and torque by the controller, there is no need for transmission gears and where it used is for optimum results when they need to remap the engines power.

There is an existing variety of electric motors that can be used for powering an electric motorcycle:

- Direct Current Motors (DC Motors)
    - Field-Wound Motors
    - Permanent Magnet Motors
    - Brushless DC Motors
- Alternating Current Motors (AC Motors)
    - Induction (Asynchronous) Motors
    - Synchronous Motors
- Hub Motors

Most the electric motorcycle manufacturers use permanent magnet AC motors as they are more simple, require almost no maintenance and deliver high power and instant torque without the need of transmission gears. As the purpose of this project is not to evaluate and propose an electric motorcycle concept from an engineering point of view, we are going to use the dimensions and specifications of the same electric motor used by an established electric motorcycle manufacturer for a model with similar use as the one we are aiming to design.

Our motorcycle should be a high-performance motorcycle, with powerful engine but at the same time, light, easily controlled, and with low need for maintenance. Thus, we are going to use also a permanent magnet AC motor.

7.3 Converters & Controllers

A controller is a electronic devise, small in size, that connects the power source (battery pack) to the motor. It controls the speed and the direction of the motor rotation and optimizes energy conversion. Some controllers require converters to step down changeable voltage coming from batteries to the motor's expected constant operating voltage.

The controller not only varies the speed and torque of the motor, eliminating the need for transmission gears, but also effects regenerative braking, during which the motor is used as a generator to recharge the batteries.

Controllers are the heart and brain of an electric motorcycle and thanks to current technology can be designed to be compatible with any type of motor and batteries and can be easily produced to be compact and fit in a motorcycle without taking too much space.

Figure 7.2: AXE4834 Alltrax AXE4834 Series Controller 300 (Altrax)

7.4 Batteries

Batteries may seem as a simple part of the motorcycle but they play a major role in the popularity of electric vehicles among motorists. Batteries are the source of energy for the motor and thus set the distance range of the motorcycle. The limited power storage efficiency of current batteries technology is the main reason why electric vehicles are not so popular although they exist since the beginning of motorized transportation.

The past two decades a lot of effort has been put in developing batteries for electric vehicles. For the moment, the results seem promising with the public policies supporting battery research and giving motives to people to use electric vehicles.

There are many types of batteries that can be used for powering and electric motorcycle. Most of the model available in the market use lithium-ion cell batteries and have reached a distance range from 100 to 200 km depending on their motor and driving speed (average 60-100km/h). Apart from lithium-ion cell batteries, different types of batteries can be used such as:

- Lead-acid batteries
- Sealed (sometimes called “VRLA”, valve-regulated lead-acid) batteries
- NiMH and NiCd batteries
- Zinc-air “regenerative” batteries

The main drawback of using batteries is their low power density. This refers to their Watt per kilo (Wh/kg). For high electric motor performance and speed or high distance range you need a massive batterie pack and this is a drawback in terms of space and weight. So, for an efficient electric motorcycle concept we need to make some compromises and set from the start the use our bike is going to have.

An electric bike used for short distances in the city in low speed should have a different configuration than one electric bike used in racing. Nonetheless, a controller can give you the luxury of having different preset configurations in the bikes computer, from which the rider can choose by the push of a button, so simple he can do it from his smartphone (fig. 7.3). Now you can customize your ride and see real-time performance statistics straight from your motorcycle.

Figure 7.3: Zero Motorcycles Mobile App (Zero Motorcycles)

8 MODELING & DESIGN

In the following chapter, we are going to present a design proposal for an electric motorcycle based on the engineering and aesthetic information we have gathered from our research.

The main factor we must consider is that the presence of a new electric motor system, with different specifications and geometry of the old traditional internal combustion engines, give us the opportunity to experiment with the design of our motorcycle, try new forms and test ideas that could not be applied so far due to engineering limitations.

8.1 SELECTION OF DRIVE SYSTEM, MOTOR & BATTERIES

For our electric motorcycle concept, we are going to use a typical permanent magnet, brushless electric motor with peak power of 70 hp (52 kW) @ 3,500 rpm and speed up to 160 km/h. The size of the motor will be around 30x95mm and total weight around 8kg.

Out battery pack will be the heaviest part of our motorcycle and will occupy most of the motorcycle volume. A typical Li-ion battery pack for a range of 260km in the city is estimated to weight around 50-100 kg and will have the dimensions of a typical mid-engine ICE motor.

The plus side is that, other than the motor, the battery and a small controller there is no need for other parts, and that leaves us with enough space to experiment with our design. There are several points that work as an advantage from the starting point, while designing an electric motorcycle (fig. 8.1):

- the overall needed parts are less in number, lowering the complexity of the motor's system
- the gas tank, traditionally placed over the engine, is no more needed living this area free to experiment
- the battery pack and the engine are compact, regarding their volume, so they can easily be placed in a composition
- there is no need for exhaust system leaving much free space
- there is no need for Clutch, meaning less weight, more free space and less complexity

The drivetrain will be a Clutchless direct chain drive. The chassis will be integrated with the battery pack and the motor of the motorcycle for further stability and lightness.

Figure 8.1: typical layout of an electric motorcycle with a battery pack and a motor with an obvious composition simplicity (voltamotorbikes.com)

8.2 GEOMETRY

Before we set the dimensions and the geometry of our motorcycle, we need to define few geometry variables.

8.2.1 Trail

As Foale describes at his book *"Trail is determined by the distance at ground level between a vertical line intersecting the wheel spindle perpendicular to the ground and a line that passes through the headstock hitting the ground at some distance away from the vertical line through the spindle"* (fig. 8.2).

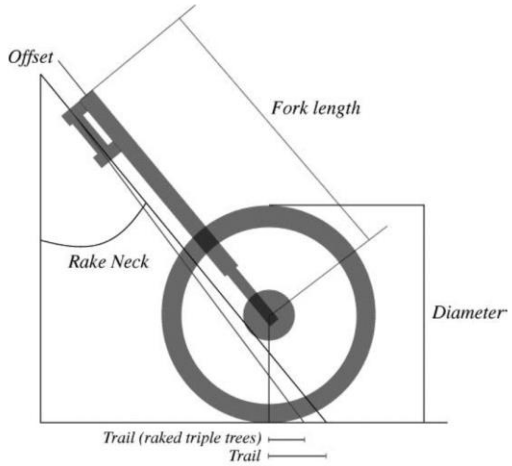


Figure 8.2: Front System Geometric Variables (Foale 2009)

Trail plays important role in the steering stability of the motorcycle and it changes depending the driving style. The higher the trail, the more stability we have during cruising in high speed. Less trail means higher maneuverability but also instability.

8.2.2 Rake or castor angle (steering axis inclination)

The angle of the headstock to the vertical line when the bike is in stasis, is referred to as the rake (fig. 8.3).

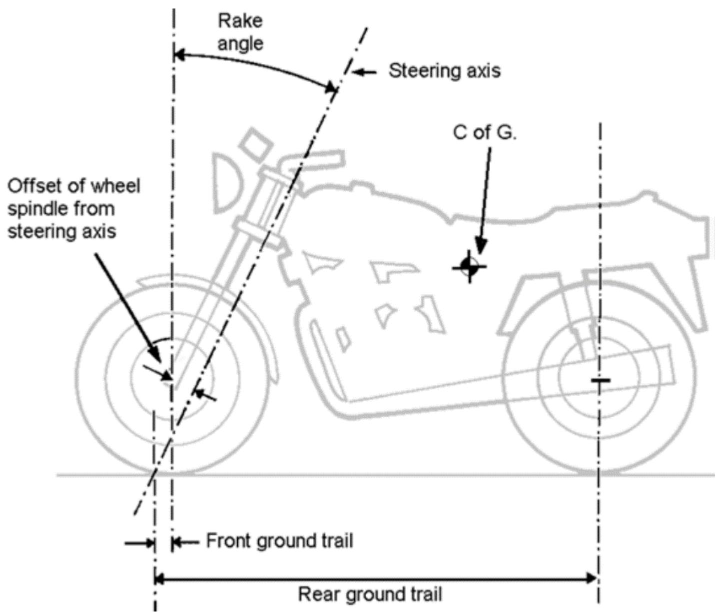


Figure 8.3: Motorcycle Geometric Variables (Foale 2009)

Most common rake angles are between 28 and 35 degrees. The rake must not be confused with the fork angle, although sometimes may be the same. Rake of the frame is a factor that as trail, affects also the steering stability and speed of the response steering. Small rake means quick response steering and thus ease at low speeds but unsteady at high speeds. On the other hand, high rake means slow steering and consequently steady at high speeds but difficult to balance in low speed or in winding rides.

8.2.3 Wheelbase

Wheelbase is the distance between the centers of the two wheels, front and rear. In general, the longer the wheelbase the greater the directional stability and the greater the effort for maneuverability.

Furthermore, wheelbase plays an extra role in the riding comfort. When riding over a bumpy road, then the movement from the bumps to the wheels will be transferred to the rider, depending whether the wheelbase is a multiple of the bump wave-length, or an odd multiple of half of the wave-length.

Additionally, under braking or acceleration, they wheelbase affects load transfer, as lengthening the wheelbase decreases the load transfer.

8.2.4 Wheel diameter

They have been many changes to wheel diameter through the time with most common in recent years to use 17 inch wheels. According to Foale, Tyres and wheel size have variant effects on the motorcycle character such as:

- For a given tyre section, a small wheel reduces both the unsprung mass (to the benefit of road holding) and the steering inertia. This is welcome in all cases.
- Wheel size also effects gyroscopic forces. For a given tyre and rim section, these forces are proportional to the road speed and the square of the wheel diameter. Thus, bigger wheels will start to give their balancing effort at lower speeds
- A smaller wheel must mount a step in a shorter time than a larger wheel, this increased vertical velocity places more demands on the suspension system and transfers more shock back to the sprung mass of the bike. So, touring machines need larger wheels for comfort and road holding on rough roads, while trials and motocross machines have 21 inch (533 mm.) front wheels, the better to ride the bumps.
- For a given tyre section, the area of rubber on the ground is generally greater with larger wheels. With smaller wheels, we could restore the area by widening the tyre (as is done in racing) but this can bring other problems, as discussed elsewhere.
- The self-steering effect of trail and rake mentioned earlier is emphasized by the use of smaller wheels.
- For purely structural reasons, smaller wheels are stiffer.

8.2.5 Weight (mass) and its position

The distribution of weight between the front and rear wheel of the bike, in stasis or in motion plays an important role in the maneuverability of the bike. Parameters like, suspension distance dive, position of swingarm pivot, height of rear axle, wheel base, center of gravity, all play important role in balancing a motorcycle during braking and acceleration.

The above parameters must be set to keep the load transfer as low as possible during braking and acceleration, as while there is a weight transfer under these two circumstances, the trail of the motorcycle changes and thus steering stability.

8.2.6 Center of gravity

The center of gravity (CoG) is a point of a body at which we can consider the body's mass concentrated. The place of CoG of a motorcycle is important for the motorcycles geometry as it affects the maneuverability and load transfer.

Placing the CG high, increases the load transfer during acceleration and the weight on the rear wheel, thereby improving the traction of the vehicle. However, in case of even higher placement, the result will be an excessive load transfer and rollover of the bike. The same applies in braking situation, only this time the force is set to the front will. In any case, low center of gravity facilitate good balance. Similarly, less total mass means better acceleration, less inertia and so less effort for controlling and handling from the rider.

8.2.7 Sprung and Unsprung Mass

Sprung mass is the mass of the motorcycle that is on top of the suspension. That means the whole motorcycle except wheels, tires, brakes and brake discs calipers and theoretically a percentage of the front and rear suspension systems, as they are not entirely part of either the sprung or the unsprung mass.

For performance evaluation, we use the ratio of sprung to unsprung mass. The ratio of sprung to unsprung mass, affects parameters like roadholding and comfort in bumpy roads, but with opposed results. For roadholding, less unsprung mass means easier response to road bumps. But there are construction limits to how light we can make the wheels. This is solved by increasing the sprung mass.

In the other hand, a high unsprung mass will increase ride comfort. Imagine a heavy wheel hitting a bump, the tire will absorb the shock and the wheel we stay almost unmoved and thus, pass less motion to the suspension and the rest of the bike making the ride smother.

From the above we understand that a compromise between roadholding and riding comfort is inevitable as we need to find the golden line between sprung and unsprung mass, depending of the type of motorcycle use we wish to have.

8.3 Ergonomics & Dimensions

To set the ergonomic parameters for designing an electric motorcycle, as Sharp proposed at his paper, we define, the damping ratio of the rider-motorcycle transfer function, as a factor of riding comfort perception. We can say that when the damping ratio increases, the rider will have a feeling of better comfort. Damping ration is a dimensionless measure describing how oscillations in a system decay after a disturbance.

There is a big difference between a conventional motorcycle and an electric one, when it comes to designing and this is the total weight of the bike. The weight of an electric motorcycle is centralized to its electric motor and batterie pack, as batteries weight more than a IC engine and a petrol and oil tank added together. Furthermore, Batteries and motor are fitted in the bottom of the chassis meaning the mass center of the electrical motorcycles is lower than those of the conventional ones, which have upper oil tank and engine placements. Those factors need to be considered when setting the geometry of an electric motorcycle as they affect handling effort and by default riding comfort.

As Lai et al. have proved in their paper, if we move the mass center forward, shorten the wheelbase, steepen the front fork rake angle and shorten the front wheel trail distance of the current design of electrical motorcycles in the market, a better perception of riding comfort is achieved.

However, all the above factors, have countereffects to motorcycle stability in different styles, meaning that again we need to experiment and compromise to get the best result with the least disadvantages, depending on the riding style we want to have, sport for racing, cruising in normal speeds, moving through traffic in low speed.

The positioning of the heavy batteries pack is of great importance as it defines the mass center of the bike. When the mass center is in the rear-top position, the rider is almost unable to stabilize the motorcycle only by the leaning movement of his body without using great steering effort (Lai 2013). Regarding the longitudinal position of the mass center it is also found that the more forward the mass center, the higher the maximum damping ratio is (Lai 2013).

Other factors affecting the stability and perception of riding comfort are:

- **Wheelbase**. Lengthening the wheelbase, in low speed, will reduce the stability and increase the rider’s effort to stabilize the bike. Additionally, it will reduce the damping ratio. On the contrary, in high speed, lengthening the wheelbase will improve the straight-line-running ability of the motorcycle.
- **Front fork rake angle**. Decreasing the front fork rake angle (steepen) will increase the stable region and the damping ratio in low speed and the rider will have a better perception of riding comfort. On the other hand, increasing the front fork rake angle will decrease the stable range and the damping ratio but as Sharp proves, in higher speed and in straight line, you will have the opposite effect.
- **Front wheel trail distance**. As the front fork rake angle increases, the front wheel trail distance has to increase correspondingly to improve the stability and the perception of riding comfort. In addition, there is a maximum damping ratio for each trail distance under different rake angles. Besides, for the same trail distance, decrease of the rake angle reduces both the stable region and the perception of riding comfort (Lai 2013).

From the above we conclude that, for medium speeds and maneuverability, moving the location of batteries forward and upward, shortening the wheelbase, decreasing the front fork rake angle and a suitable trail angle, gives us a better perception of riding comfort.

Another factor that we have to take into account regarding riding comfort is the ergonomic triangle. The ergonomic triangle is achieved by combining virtual lines that passes through specific points of the motorcycle. Those points are the saddle, the handle bars and the foot pedals (fig. 8.4).

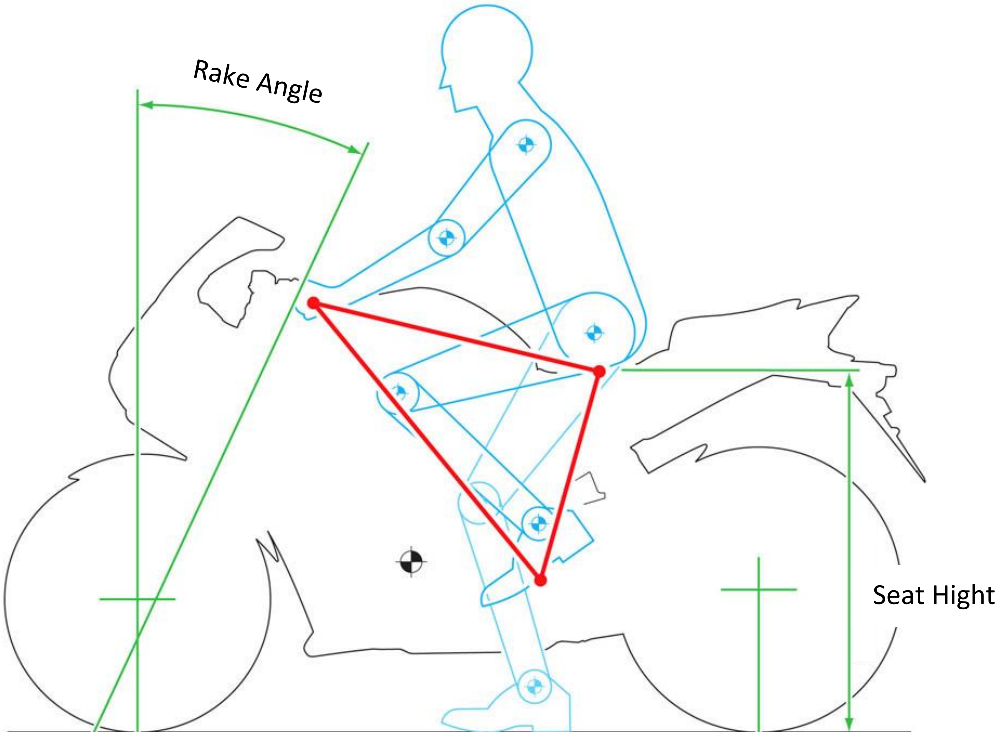


Figure 8.4: Ergonomic Triangle (Wong 2016)

The distance between this points as also the angle of the lines in relationship with a horizontal line affect the comfort of the ride. The triangle should be researched relatively to the use of the motorcycle. A touring motorcycle, that a rider would drive for longer times should have an upright position to avoid pain in joints and back and to reduce pressure on hands. On the other hand, to a racing bike, performance comes first than comfort and so in order to reduce air drag a more aggressive position is needed, with the body crouching over the bike and feet pedals pulled up so in leaning of the bike, nothing will scratch the asphalt, causing a fall.

The best solution, as there is no universal sizes and optimum fixed positions, is to give the ability for the rider to optimize his riding position by adjustable parts in the three points of the ergonomic triangle. Naturally this is not always the case, as there are limits to how flexible position your motorcycle parts can have. In that case, you have to compromise.

The important factors are:

- The position of the handlebars
- The inclination of the fork
- The width of the handlebars. Wider means easier to steer with less effort but also means more air resistance and exposure
- Height of the saddle

- Height of the foot pedals
- Distance between foot pedals and saddle

The same applies of course for the riding position of the passenger, who should be able to keep himself on the motorcycle without interfering with the riders ability to drive or with the stability of the motorcycle, as, although his role in stabilizing the bike is important, most of the passengers and inexperienced and adopt a passive position.

For our concept motorcycle, we have defined the dimensions as follows:

- Wheel base: 1.476 mm
- Rim/front: 3.50 x 17"
- Rim/rear: 5.50 x 17"
- Tyres/front: 120/70 ZR 17
- Tyres/rear: 180/55 ZR 17
- Length: 2.220 mm
- Seat height: 785 mm
- Handlers height (excl. mirrors): 1.265 mm

All the above dimensions were taken approximately, according to existing ICE models that have similar road use as the one intended for our concept. To produce different propositions and experiment with our form of our motorcycle we have set our dimensions in a basic sketch and used it for each concept (fig. 8.5).

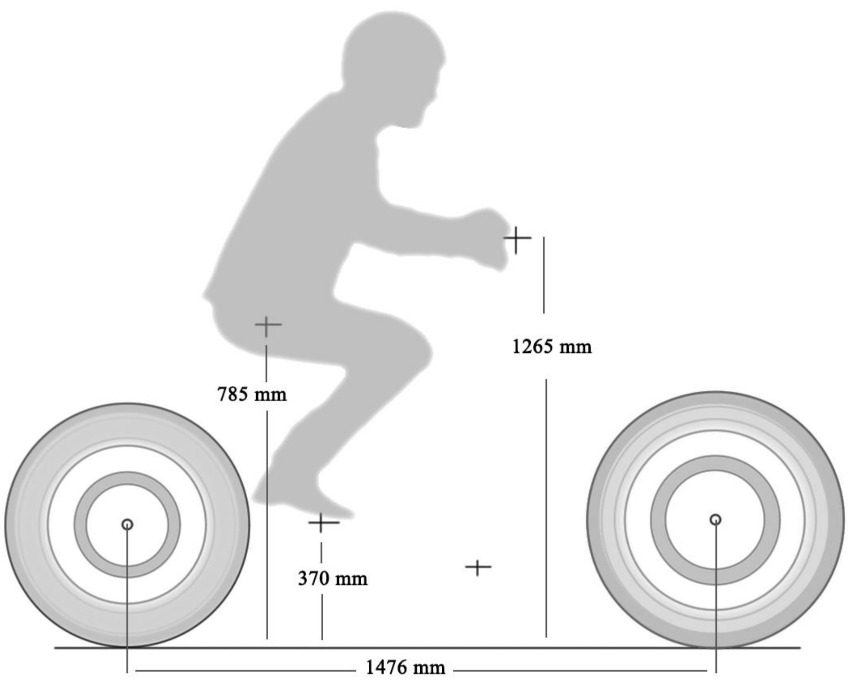


Figure 8.5: standardized dimensions for our concept electric motorcycle

8.4 DESIGN TRADE OFFS

In every new concept project, the designer wants to design the perfect product, ideal for any use, covering as much as possible, every need of its target group. But this is not possible. There is always the need for tradeoffs and compromises and key to success is to find the balance between “wants” and “haves”.

Our electric motorcycle will be mostly used in urban environment. This means that we must keep its figure slim and its weight low so it can maneuver through traffic. As an electric motorcycle, its range depends on the battery pack, and if we want to give our motorcycle a high range we need to add more weight and volume due to larger battery pack. Consequently, the range of motorcycle need to be constrained to 200km maximum, in city riding.

Furthermore, a sport bike look, with low handlebar, steeper steering angle and more crouching riding position has an aesthetic advantage as it is more aggressive, nonetheless, for a motorcycle used every day in the city, from our target group as described above, this would not be practical and thus the handlebars are put in a higher position for a straighter riding posture.

8.5 CHASSIS

From the beginning of the motorcycle history, chassis technology was developed alongside with engines in a basis of covering the need for the support of more powerful engines. From the first time a motor was fitted onto a bicycle frame the experimentation for stiffer and lighter chassis was a focus.

Today, with the electric motors, the specifications have changed as they produce different torques and deliver power in a different way.

The role of a motorcycle chassis has two dimensions, static and dynamic. In a static sense, the motorcycle frame must support the weight of all the other motorcycle parts and the riders. In a dynamic sense, chassis plays an important role in steering precision, roadholding and ride comfort.

For steering precision, the frame should resist torsion and bending to keep the steering axes in the same plane as the rear wheel so as the geometry of the motorcycle remains unchanged. Additionally, the frame should sustain fatigue for a long lifetime without the need of maintenance.

A point that it may seems unimportant but relates to handling is the stiffness of the frame supporting the seat. If the frame is not rigid enough to transfer the correct feedback from the road to the driver, then the feeling is left will be wrong and the rider will make wrong corrections. A rider gets its feedback not only from the steering but from the whole body of the motorcycle and thus the frame.

There are many types of frames used throughout the motorcycle history:

- Tubular frames
    - Diamond pattern frame
        - Single loop frame
        - Cradle frame (fig. 8.6)
        - Duplex cradle frame
    - Cotton frame
    - Francis-Barnett (fig. 8.7)
    - Scott frame (fig. 8.8)
    - Featherbed (fig. 8.9)

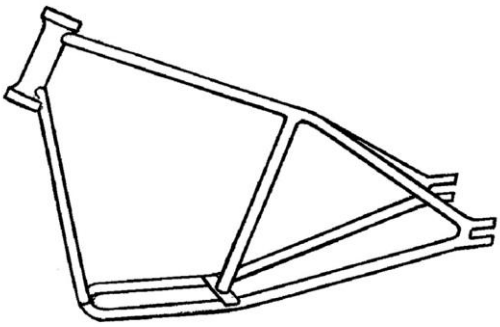


Figure 8.6 Tubular Cradle Frame (Foale 2002)

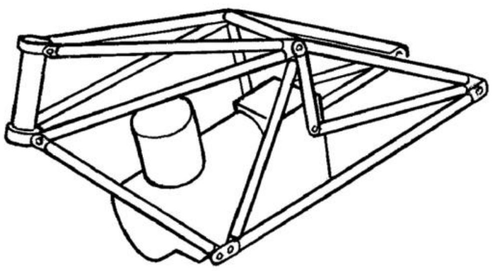
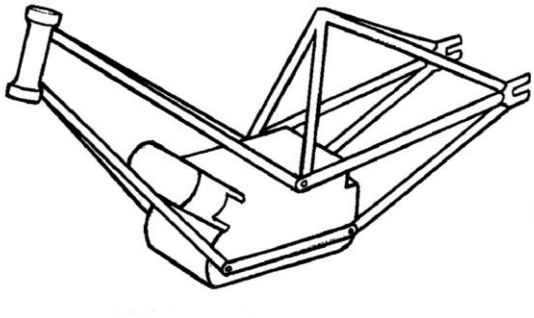


Figure 8.7: Francis-Barnett Frame (Foale 2002)



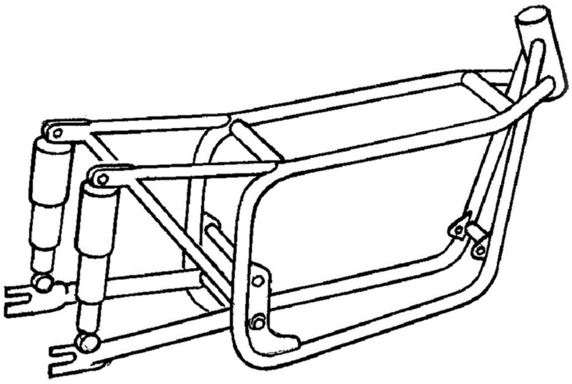


Figure 8.8: Scott Frame (Foale 2002) *Figure 8.9: Featherbed Frame (Foale 2002)*

One of the most commonly used frame in the 50s designed by Norton and used on their racers was the Featherbird, a duplex-loop layout with mediocre structural efficiency but provided adequate stiffness and a fairly even weight distribution and a relatively low centre of gravity. In generally, steel has been the most common material for tubular frames but also both titanium and aluminium have been used.

- Beams
    - Twin Spar frame
    - Ariel Leader frame
    - Arrow frame

For those type of frames, large-diameter tubes were used as the main frame member, thus combining a high degree of stiffness with simplicity and light weight (fig. 8.10). The main goal to a frame design is to directly connect with a straight tube the steering head with the rear wheel, which is usually impractical. These frames have been made in both steel and aluminium, which is currently the material of choice.

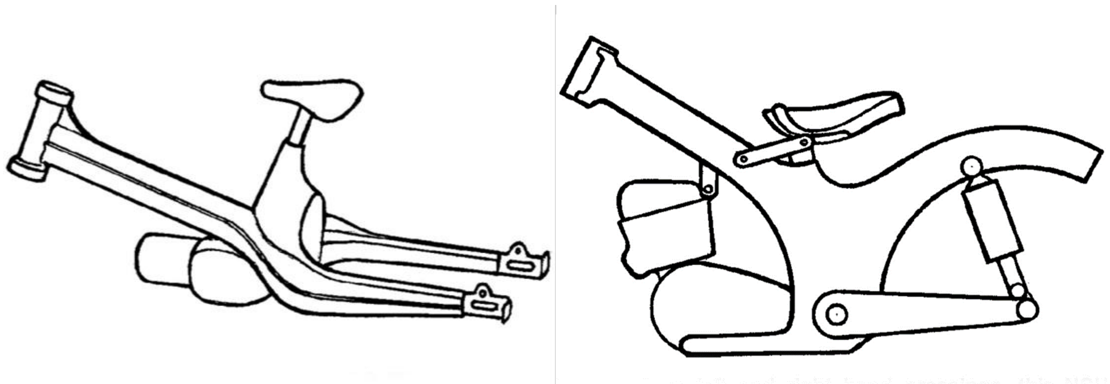


Figure 8.10: Beam frames (foale 2002)

- Hub-Centre steering (Ner-a-Car, 1920) (fig. 8.11)

Hub-center steering, is a solution that solves many stability and roadhoalding problems but at the same time increases complexity. It will be further described in latter chapter.

Figure 8.11: Ner-a-Car

- Use of the engine as an integral part of the frame (fig. 8.12)

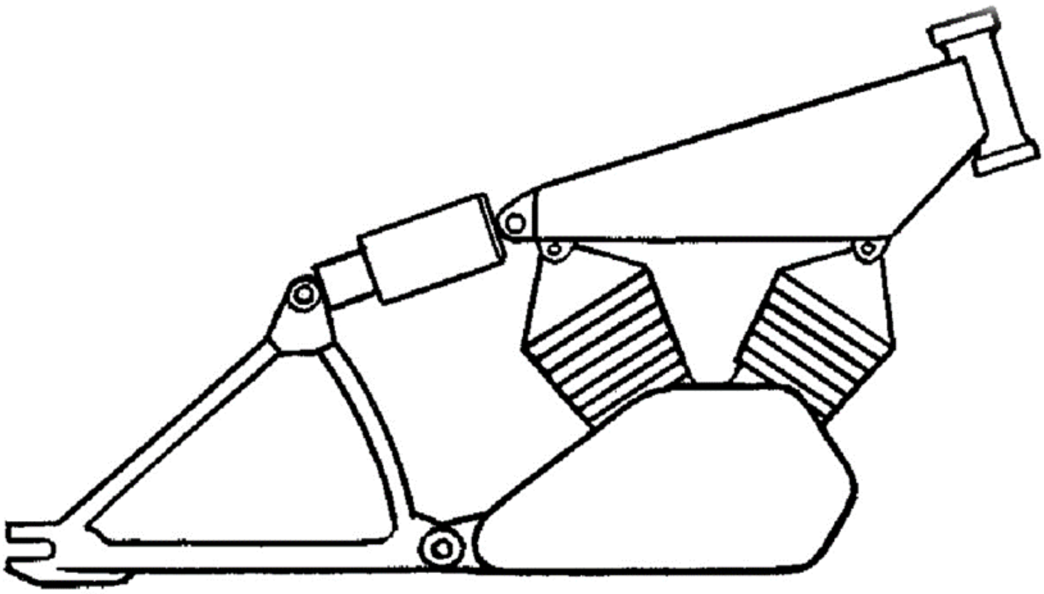


Figure 8.12: Vincent V-twins (Foale 2002)

For our design, we are going to integrate the electric motor and battery pack as part of the chassis. The lack of gas tank and the hub-center steering, give us the ability of a direct connection between the front and the rear wheel, keeping the center of gravity low and the stability performance higher. The chassis layout of our concept will be similar to the one used by Johammer motorcycles (fig. 7.19).

8.6 SUSPENSION

Suspension is a dynamic system, consisted from springs and dumpers, part for sprung and unsprung masses. Suspension system includes, theoretically, also tires, as they absorb most of the road irregularities.

The benefits of the suspension regarding riding comfort are undoubtable. In the other hand we have to compromise to a level as we have to take into account behavior under braking, load transfer, acceleration, cornering so as to set up out suspension for the best and safer performance. We do not want for example, to make our suspension soft for riding comfort and in a situation of intense braking, the dive would be so low that we will lose stability and control of our bike.

Current telescopic forks offer many advantages and are highly evolved under racing, testing and research. Nonetheless they are not the best solution rother than the cheapest, lest complex, easiest to mass produce and with less effort to maintain.

Some of the basic engineering problem areas inherent in telescopic forks are (Foale 2002):

- When the fork is fully extended, because of the reduced overlap, there is minimum support for the sliders.
- The sliders can move independently of one another.
- Considering the loads applied on them, the stanchions are quite small.
- Under braking this type of fork is usually subject to a great amount of nose dive.
- Because of the rake angle, bending loads are applied to the fork legs under static loading and this gives rise to stiction, which hardens the response to small.

The forces that apply to forks during braking and turning may change their geometry and make their performance inadequate. Hub-center steering offers a more robust solution but complexity of this front system makes it inappropriate for mass production.

8.6.1 Front System- Hub Center Steering

As motorcycles becoming more and more advanced and powerful, it is important to eliminate any engineering disadvantage current motorcycle technology has. Hub Centre steering can eliminate the major problems involved with the front telescopic fork suspensions (Wadibhasme et al. 2014), lateral wheel displacement and limited front wheel braking force.

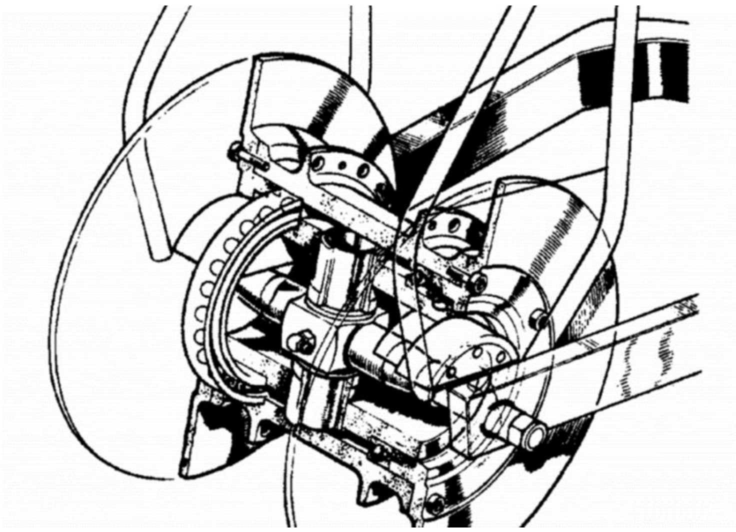


Figure 8.13: The Difazio Hub Center Steering System (Foale 2002)

Hub Center design has been around since the early 1900's (Ner-A-Car). In the 1970s through the work of Jack Difazio (fig. 8.13) in the UK, came back to surface Popularity of the telescopic forks among manufacturers, for economic reason, restrained Hub-center steering to only few concept projects, from time to time. Nonetheless, its advantages make it a good solution for our design as we do not have to think in terms of low production cost.

Hub center steering is consisted by a one or, in some cases, two swing arms, extending from the bottom of the engine/frame, directly to the center of the front wheel, connected through bearings to the wheel (fig. 8.14). Any braking force are directed horizontally through the swing arm to the body of the bike without interfering with the vertical suspension forces. Furthermore, the swing arm, forms a theoretical parallelogram which maintains steering geometry, allowing agility and consistency of steering that forks currently cannot get close to attaining (Wadibhasme et al. 2014).

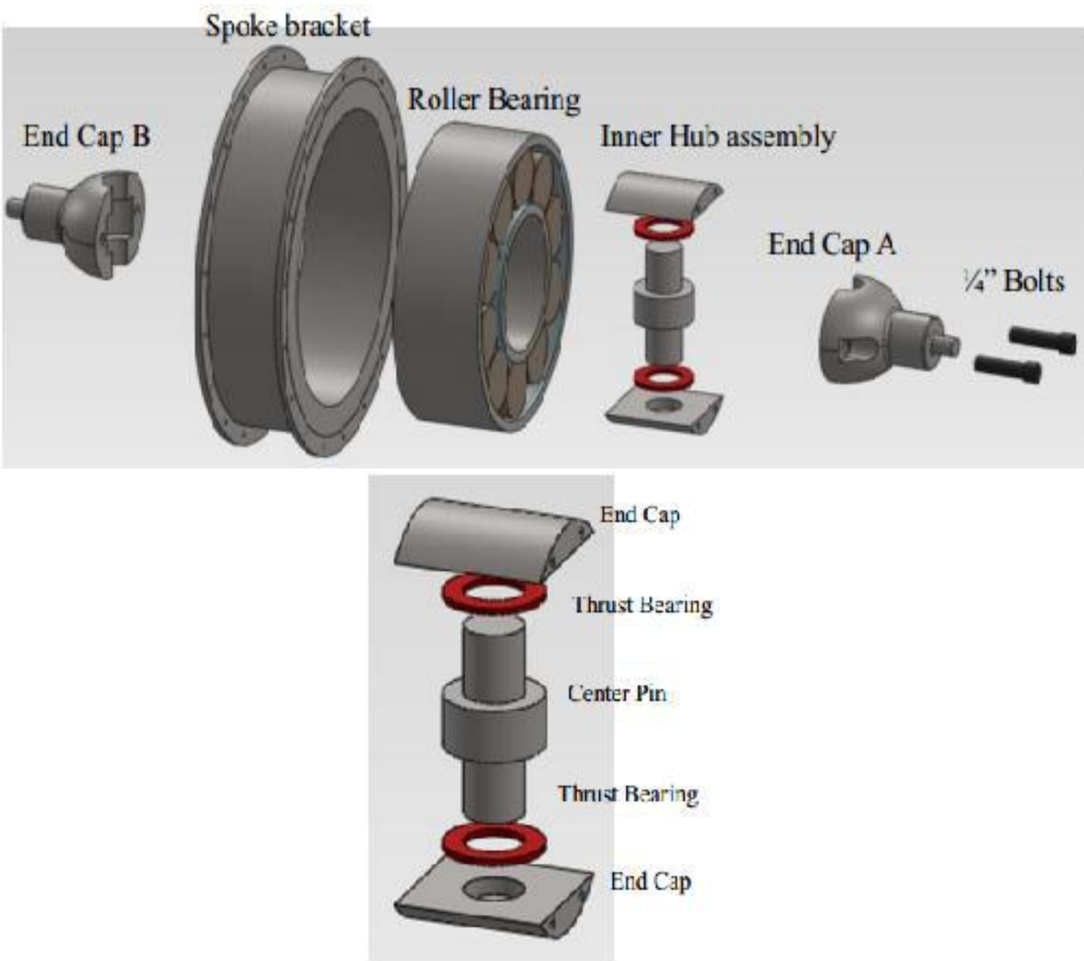


Figure 8.14: Hub center assembly (Wadibhasme et al. 2014)

Hub center steering consists of (fig. 8.14):

- Outer Hub
  - Spoke Bracket with the disk brake
  - Roller Bearing
- Inner Hub Assembly
  - Top Caps
  - Thrust Bearing
  - Centre Pin

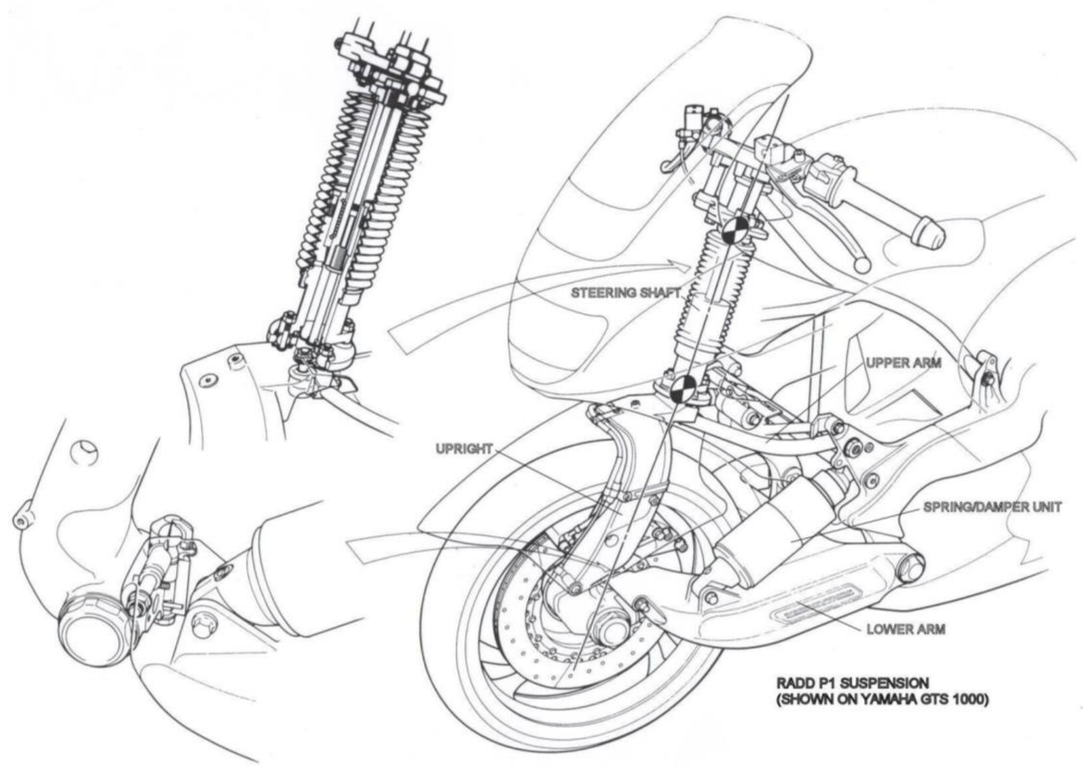


Figure 8.15: Yamaha GTS1000 (Yamaha)

Naturally there are some disadvantages. First, the reduced steering feeling. The steering is controlled by linkages and this reduces the amount of feedback transmitted from the front wheel to the rider. Moreover, the range of wheel turn is limited, compared to the one of telescopic forks, as swing arms, get in the way. Lastly, system complexity makes it hard to maintain even in simple situations as change the tire.

In time, few motorcycle brands have applied Hub center steering or a similar version to their production models such as, Yamaha GTS1000 (fig. 8.15), Bimota Tesi 3D and Vyrus 984C3 2V

8.7 REAR SYSTEM

Rear suspension did not follow the same history line as the front suspension. For many decades, motorcycles had only front suspension, with the rear wheel mounted directly to the motorcycle frame. It was latter that the advantages of a rear suspension drove engineers to add rear suspension to their chassis.

There are many types of rear suspension, all offering many advantages and disadvantages. For our concept, we will use the Monoshock Regular H Swingarm (fig. 8.16) appeared in the 70's for production motorcycle. It has existed since the 30's but mostly for racing motorcycle. This design offered more strength to the swingarm with less weight, by removing one of the coil-over units.

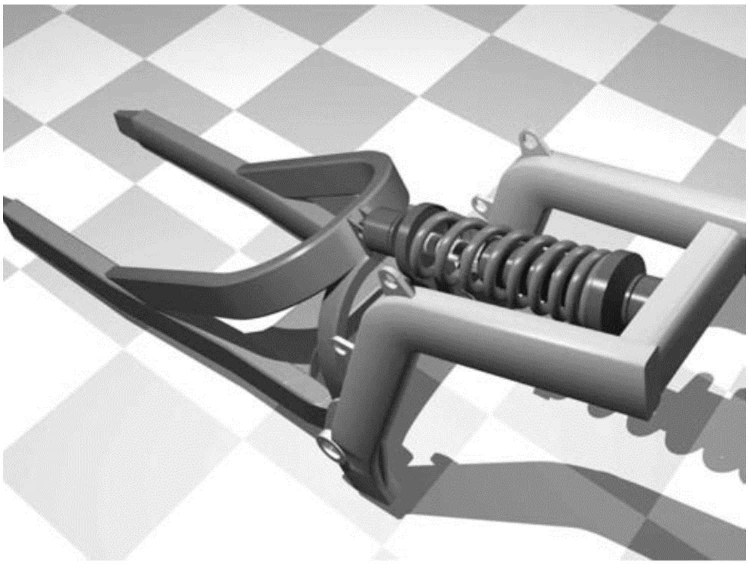


Figure 8.16: Monoshock H-style swingarm rear suspension (carbibles)

9 CONCEPTUALIZATION & FINAL DESIGN

Having the dimensions of our key points fixed (fig. 8.5), we have sketched a sum of fourteen side views of different concepts presented below. The following 14 sketches were completed in less than an hour each, and the purpose of this fast exercise was to produce unbiased ideas and fresh forms.

In some sketches, there is still the feeling of a gas tank, with a different use. In others, the tank line was removed. The use of fairing was also tested but not as a full body fairing. At this stage, the details and functionality was not of high importance and were left aside in order to enhance creativity.

9.1 CONCEPT SKETCHES

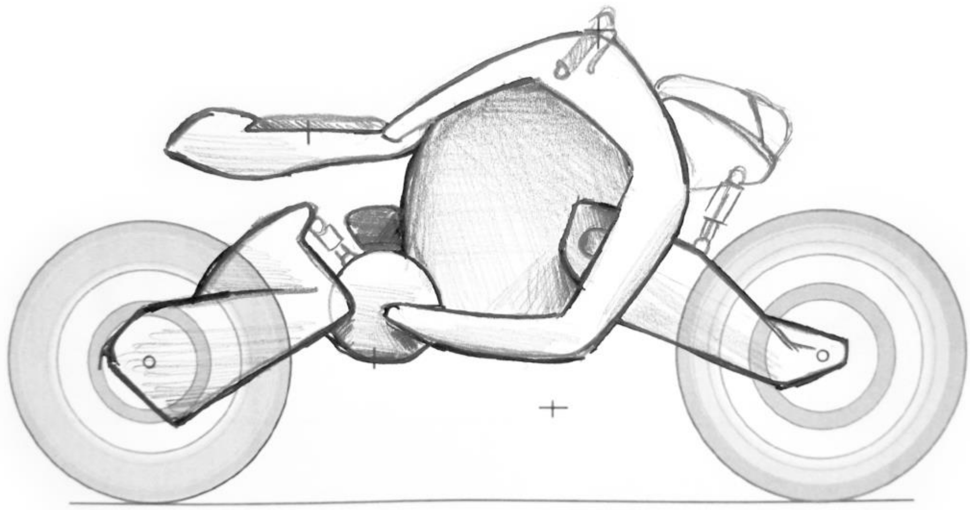


Figure 9.1: Sketch 1

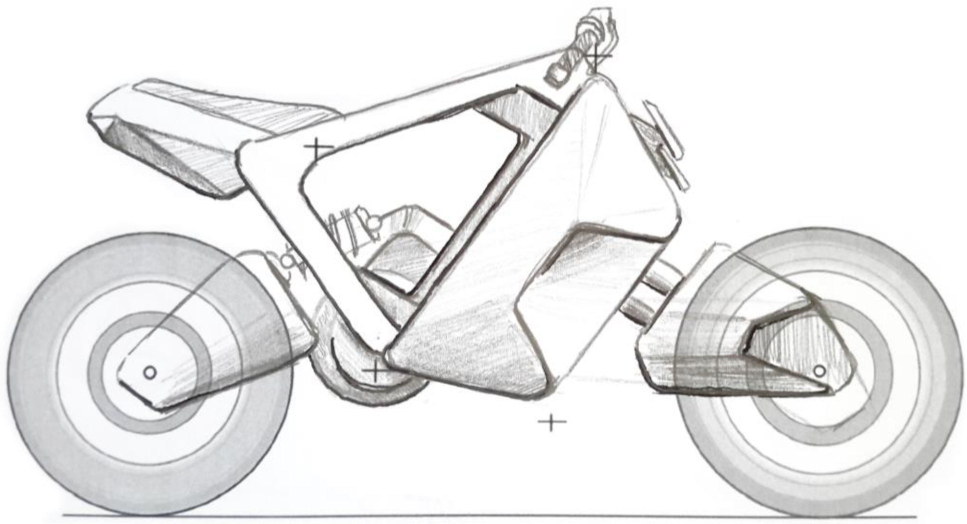


Figure 9.2: Sketch 2

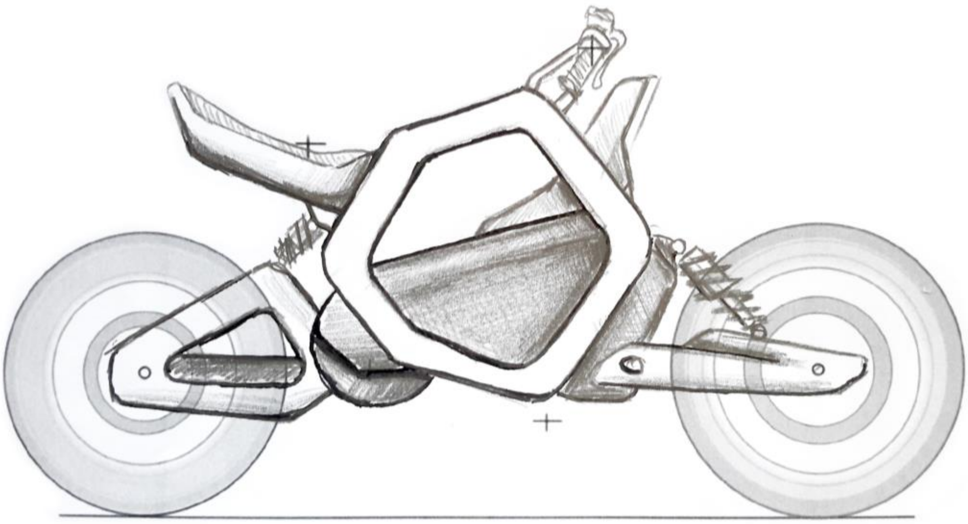


Figure 9.3: Sketch 3

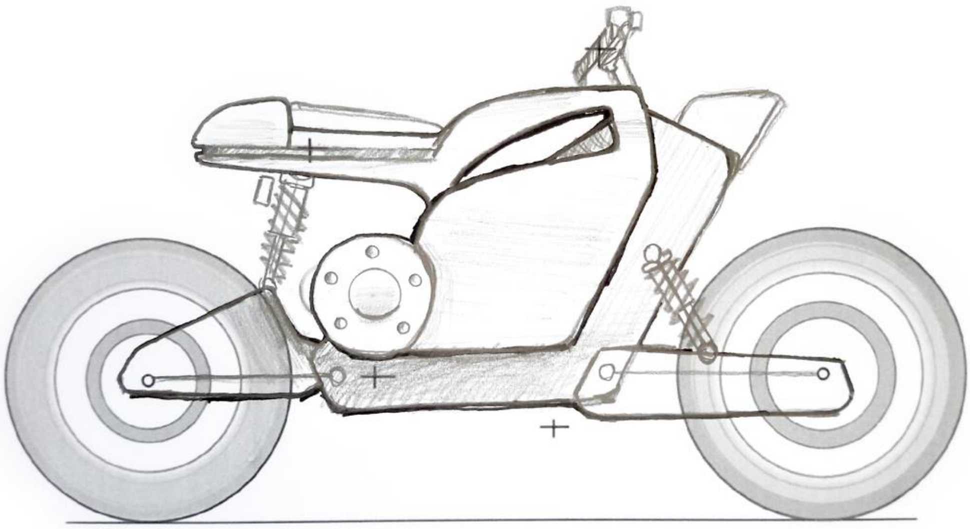


Figure 9.4: Sketch 4

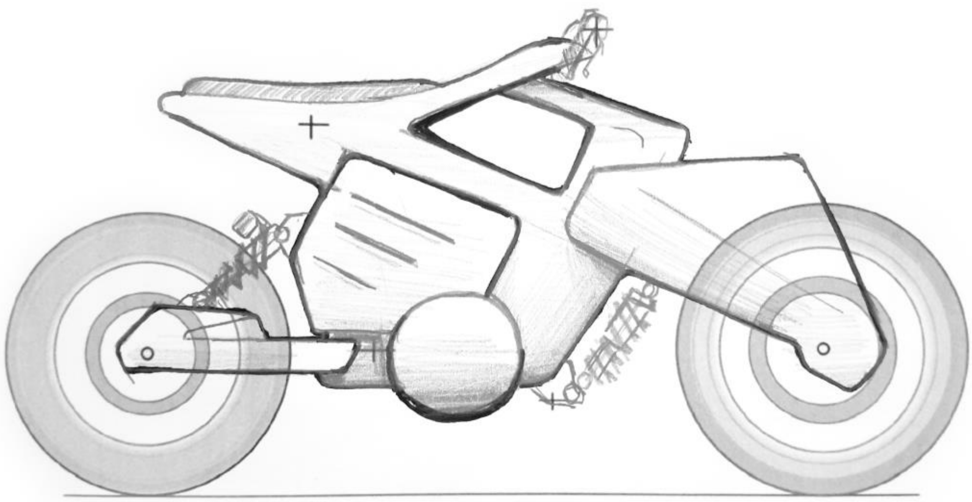


Figure 9.5: Sketch 5

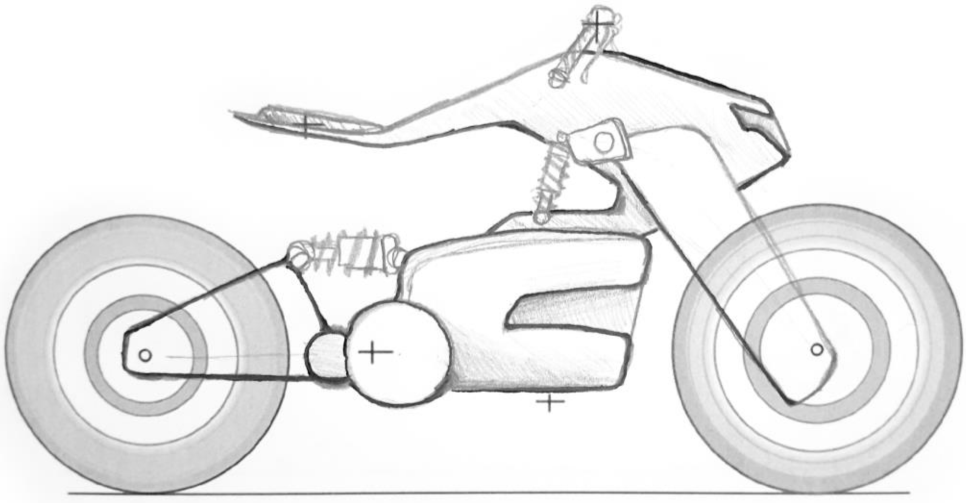


Figure 9.6: Sketch 6

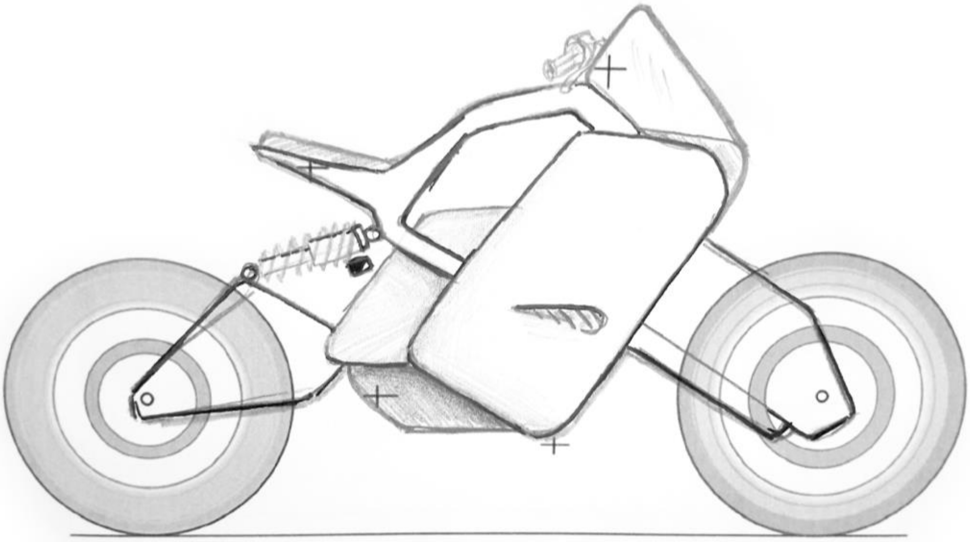


Figure 9.7: Sketch 7

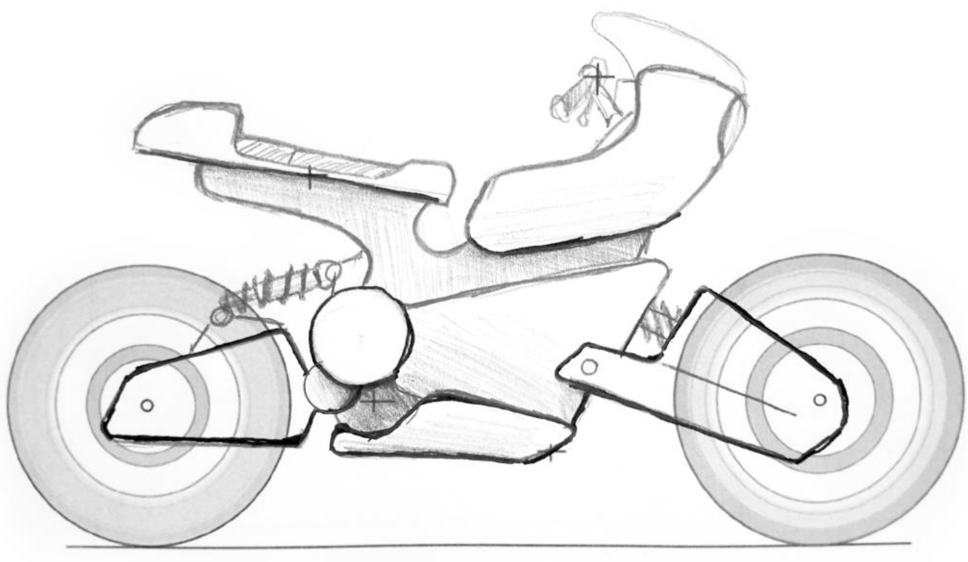


Figure 9.8: Sketch 8

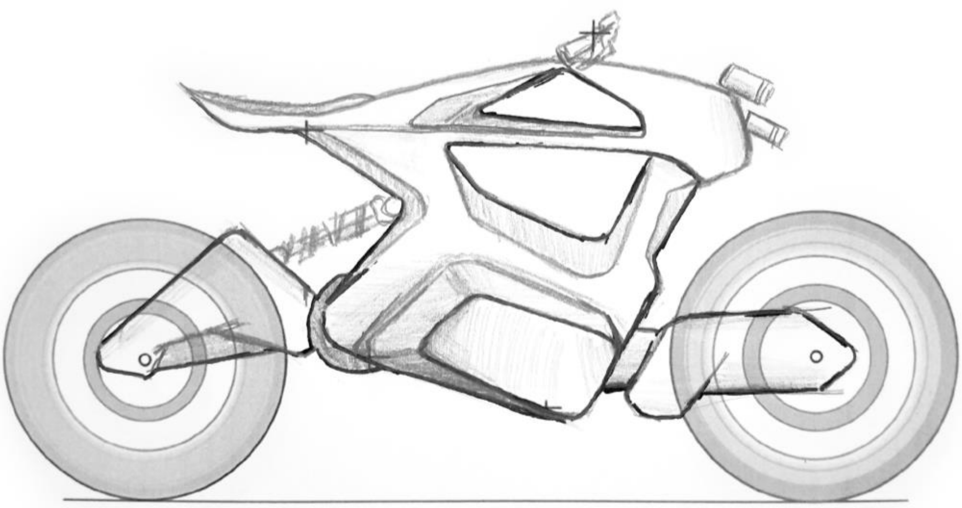


Figure 9.9: Sketch 9

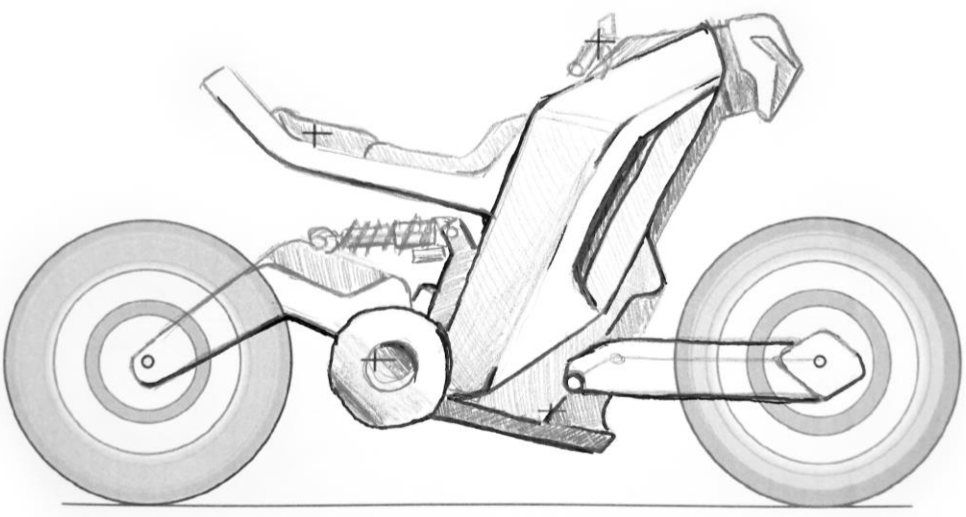


Figure 9.10: Sketch 10

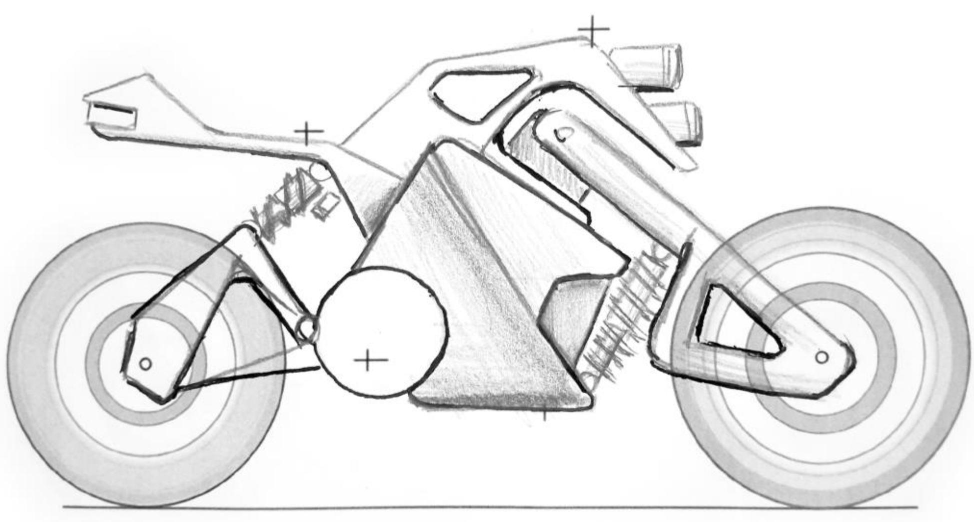


Figure 9.11: Sketch 11

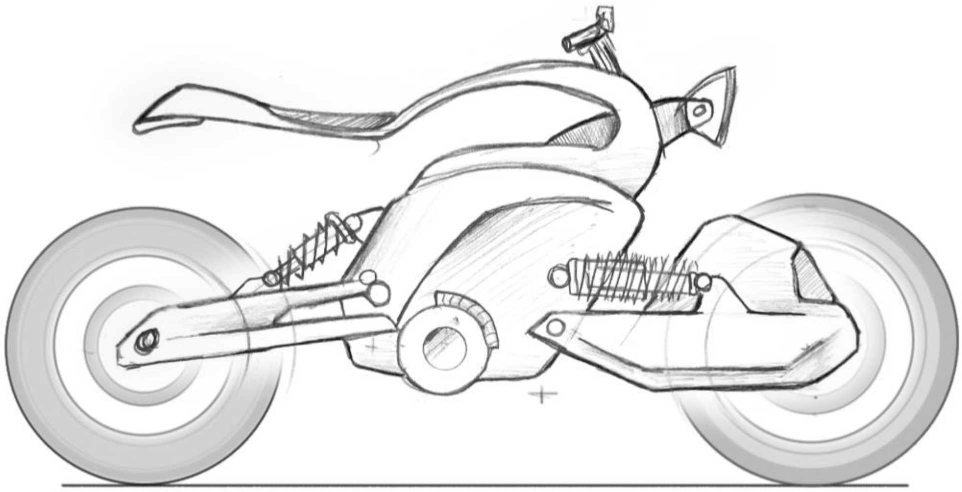


Figure 9.12: Sketch 12

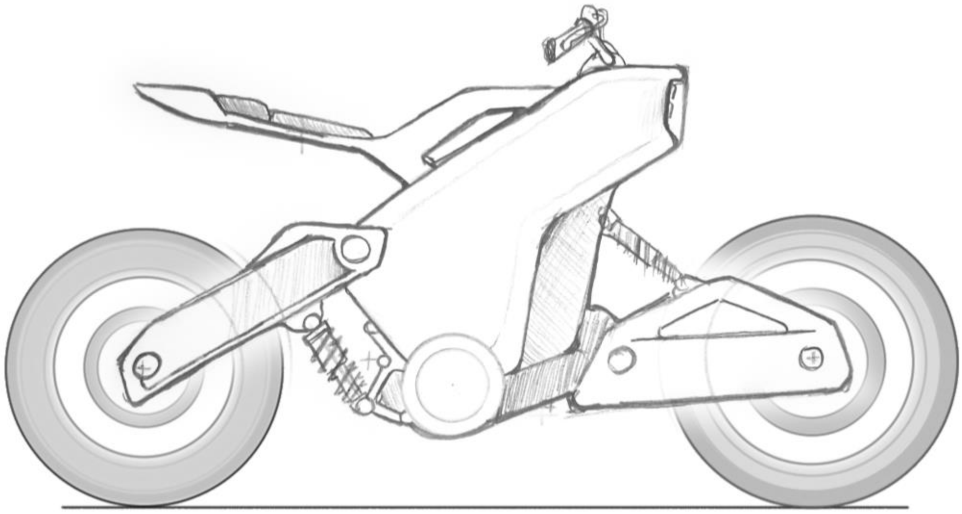


Figure 9.13: Sketch 13

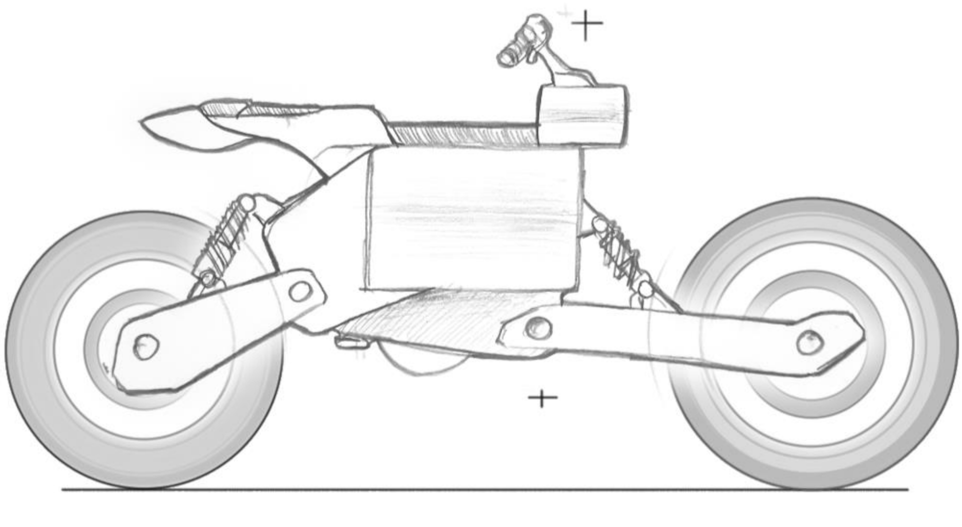


Figure 9.14: Sketch 14

9.2 Variations of Selected Sketch

Sketch 2 (fig. 9.15) was selected for further development and final render. The decision was based to the fact that sketch 2 complies with the described specifications for our concept electric motorcycle:

- Hub center steering
- Monoshock swing arm
- Within the dimension's restrictions
- It presents a dynamic and aggressive look
- It is detached from the typical gas tank line of the ICE motorcycles without leaving an awkward sense of emptiness.
- The basic structure and chassis leaves room for number of form variations

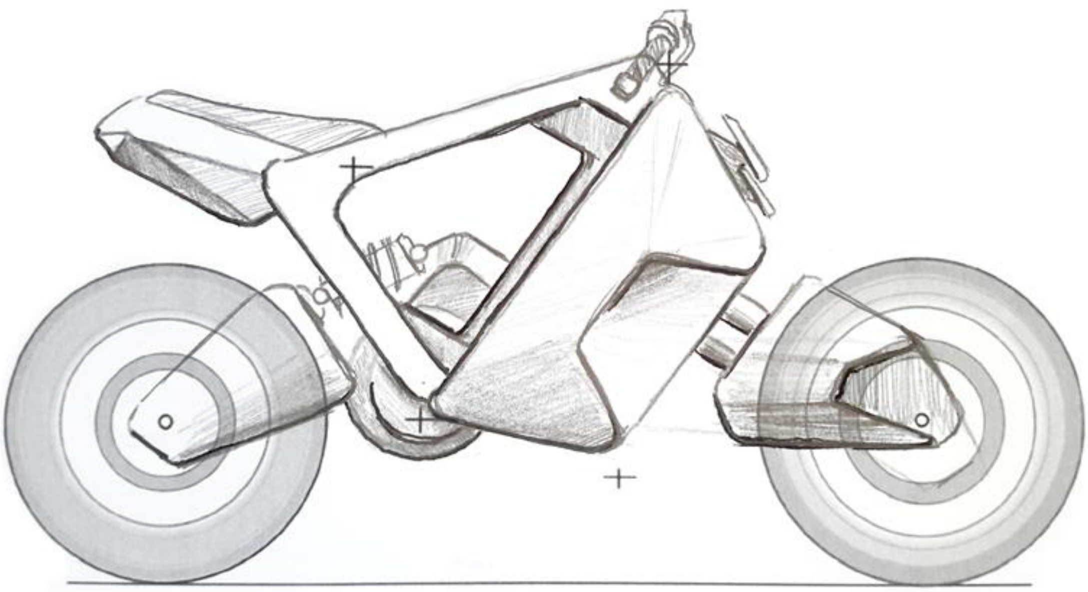


Figure 9.15: Sketch 2 was selected for further development

Having selected our body basic line for our concept, we sketched few more variations to explore more the shape of our concept.

We focused mainly on the fairing, saddle frame and headlights and produced side, front and back perspective views which communicate better our thoughts and give you the possibility to research volumes and proportions of individual parts of the motorcycle.

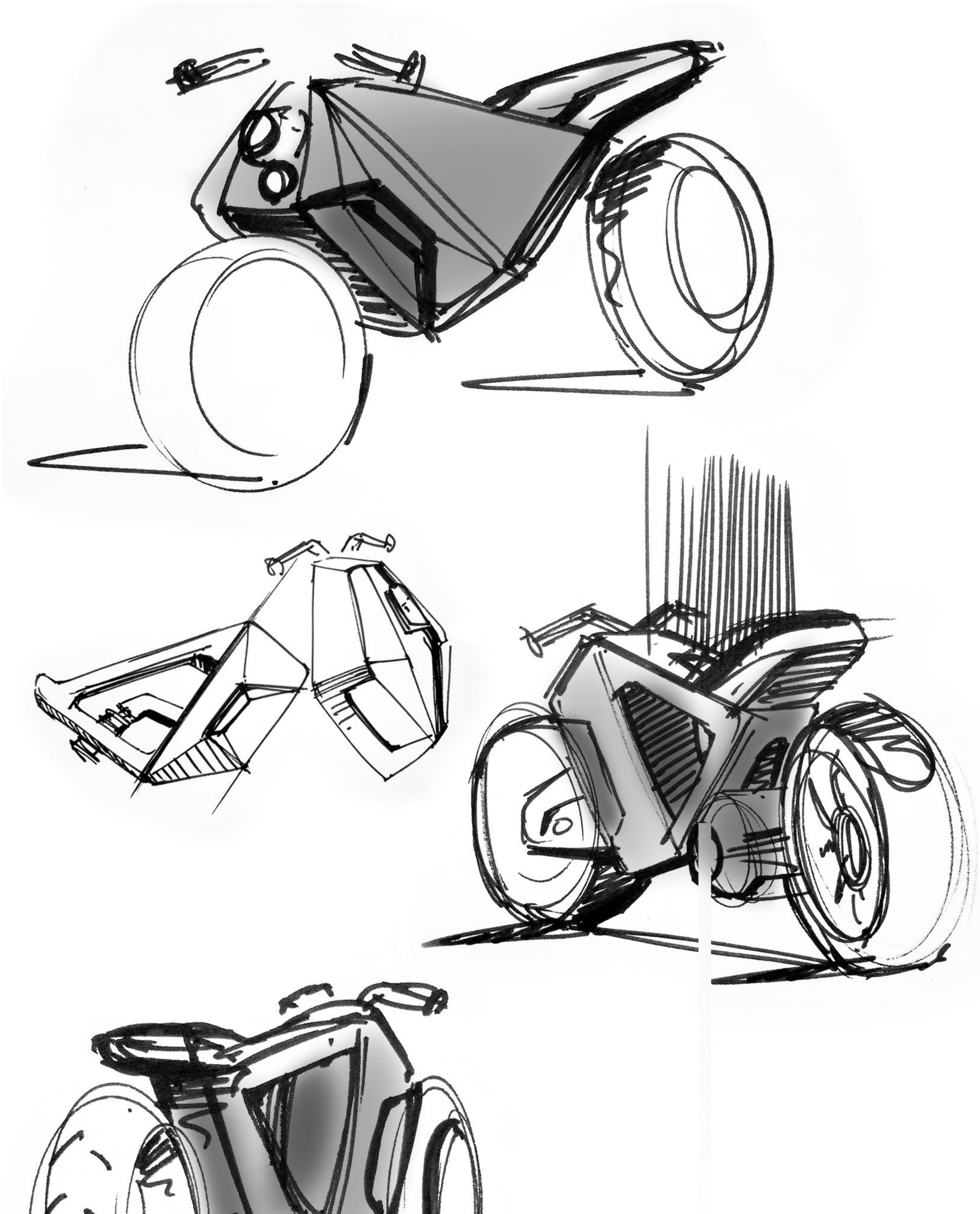


Figure 9.16: Version 1

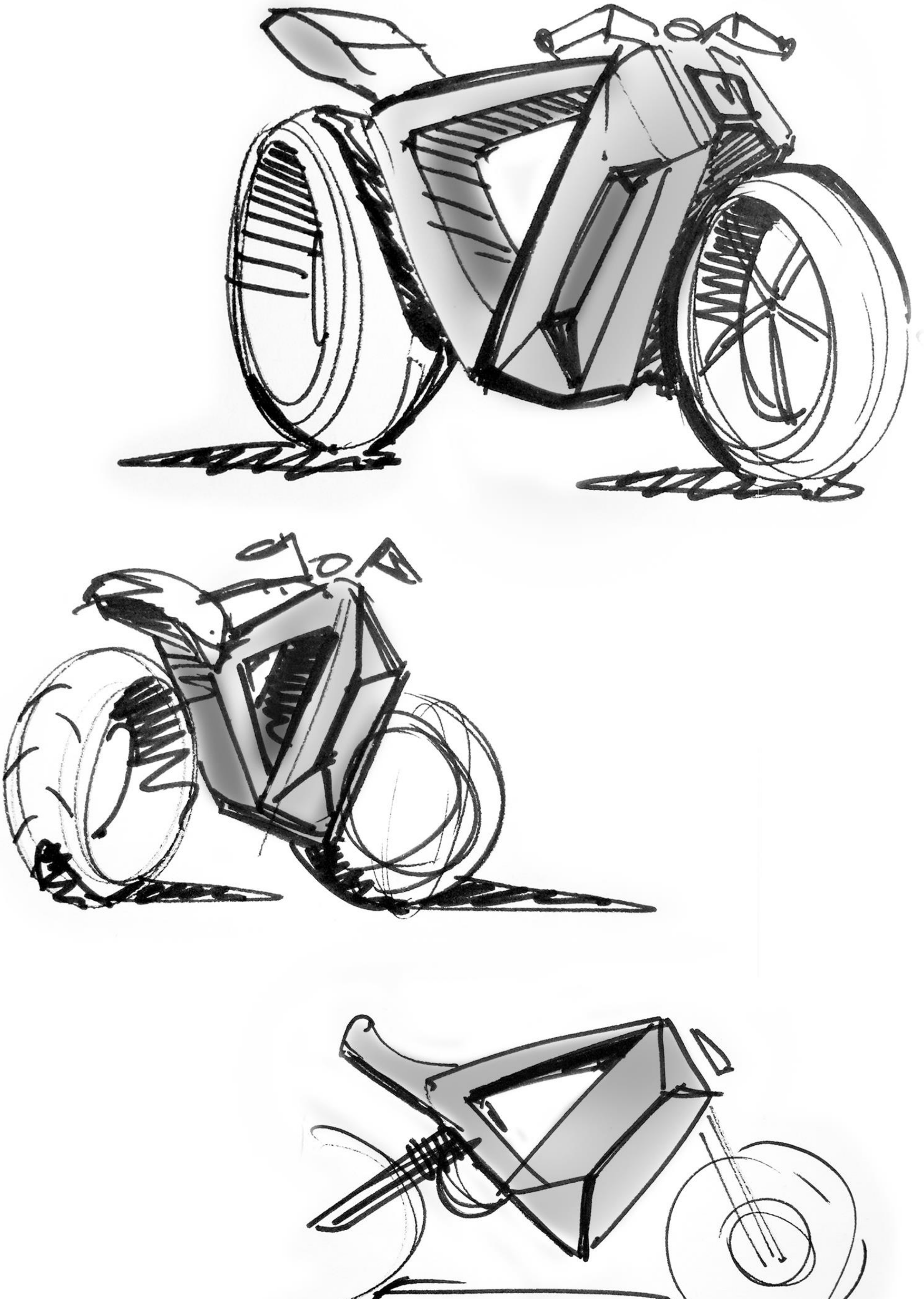


Figure 9.17: Version 2

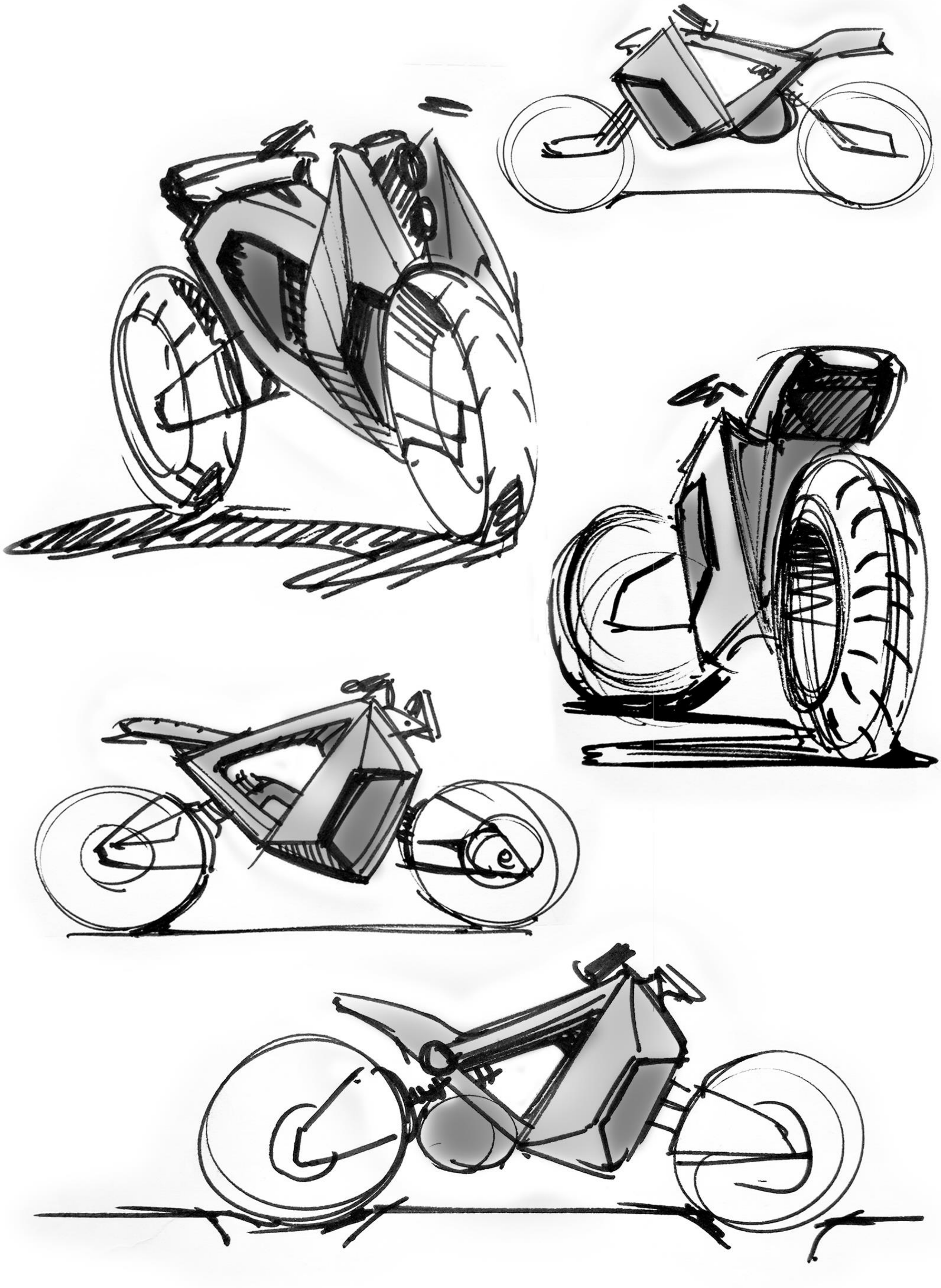


Figure 9.18: Version 3

9.3 Final Render

For final presentation of our concept we selected to render two versions of our concept. Combining ideas from all three of our above versions. The renders were produced using Adobe Photoshop.

Figure 9.19: Render 1

Figure 9.20: Render 2

10 CONCLUSIONS

Electric Motorcycles have a long way until they will become well established. Their technology is mostly new, their performance and range is relatively low but their advantages regarding economy, environmental sustainability and engineering reliability set them as a future good investment. Motorcycle riders love their Internal Combustion Engines (ICE), they love the sound, the vibrations, the smell of gasoline but most of all the love power, speed, torque, performance, style, image, individuality.

It is our obligation, as designers, to take this new technology and explore with an open mind the motorcycle archetype. Having the need for heavy battery packs as the only restriction we can develop endless variations of the modern motorcycle without lingering on shapes and forms of the past. When battery technology reaches the level of evolution that are expected, it is only a matter of raw creativity, afterwards, to attract the traditional motorists in this new chapter of the motorcycle history.

As we mentioned at the beginning, motorcycle design is an engineering game. It does not only relate to the mechanics behind the development but also tries to enhance them and project them to the riders and the people viewing the motorcycle passing by. It is an assembly of small details that come together in harmony without losing their individuality. Thus, it is important to understand the mechanics behind a motorcycle and try not to cover it under a full body fairing, as it happens in automotive design, but externalize it to the eye.

Finally, the latest turn of users to design of the past, to genuine shapes and simple forms is a suggested design guideline for mass produced motorcycles but not mass developed. Brand identity, background history, rider's networking and community, in-factory customization, can enhance the love of a motorist for the motorcycle we will design and make him a follower and not just a user, customer, owner.

In our project, we have established the first steps for a developing a new concept for an electric motorcycle. It is a project that will take a lot of time and different disciplines to complete. For further process, the development of a 3D model is required to have a full image of the geometry, volume proportions and design identity of the motorcycle. Unfortunately, this exceeds the limits of a dissertation thesis for a MSc but the research will continue outside the context of the Master Course as personal project. My goal for the future is to present a full proposal for an electric motorcycle, researched and described in all levels and ready to be produced.

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