Urban E-Mobility - Challenges and Potential Solutions using the Example of the “E3W” Concept Vehicle

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Abstract
Due to the increasing number of people in urban areas, there is a need for affordable individual transportation. Limited space in cities together with the need for a significant reduction of pollution will lead to new mobility concepts in the near future. The aim of these concepts is not replacing the car itself, but to supply an additional personal transportation solution with local zero emission. Therefore, electrical powered vehicle concepts may be used. Due to the limited energy density and high cost of current Li-ion batteries, a significant weight reduction of the vehicle could lead to acceptable range and cost. In order to develop an affordable urban concept, the requirements for this kind of vehicle also have to be adjusted in comparison to conventional cars. This concept, the so called “E3W”, combines the advantages of a two-wheeler with those of a four-wheeler, resulting in a lightweight and compact vehicle. This concept accommodates space for two persons with luggage and guarantees a high level of safety including wind and weather protection. The overall measures of this vehicle are smaller than current compact cars and allow therefore better use in cities. In order to fulfill technical and commercial requirements, a load carrying, short fiber reinforced thermoplastic body structure is chosen, combining good weight specific mechanical properties and low production costs. This highly integrated body structure also provides the body cover all in one. Pultruded glass fiber reinforced plastic (GFRP) beams are used as the backbone for the vehicle by carrying the main loads, the front crash structure and the rear swingarm. Finally, two prototypes are built to investigate the driving behavior, proof the concept and the suitability for daily use.

Keywords: e-Mobility, E3W, lightweight, reinforced plastics

INTRODUCTION
E-mobility concepts are not an invention of the 21th century. The root of this technology is reaching far behind, based on the proof of applicability for daily use of electric engines in the 1830 and the invention of lead accumulator in 1859 [1]. At the turn of the 20th century, combustion engines competed with electric engines in the car industry. As an example, in 1897 more than 100 electric vehicles existed in New York [2]. Multiple factors influenced that combustion engines overruled electric concepts in the early years of the 20th century. One main drawback of electrical powered cars in this time was the limited available electrical storage capacity and supply infrastructure [2]. Current improvements in battery systems together with new lightweight materials and engine concepts as well as new charging strategies [3] lead to a new attractiveness of electrical powered concepts. The need for global and local reduction of emissions (see e.g., [4]) together with further regulations especially in big cities, e.g., noise reduction or car limitation [5], enhance the trend for electric vehicles.

REQUIREMENTS FOR URBAN E-MOBILITY CONCEPTS
Although a big progress in battery technology has been made in the last years, electrical storage systems still have a drawback in energy density compared to conventional fuel. Even new future developments such as Li-Air Batteries with theoretical energy densities of approximately 1300Wh/kg (see e.g., [6]) cannot compete with fuel (approximately 10 times higher energy density). Therefore, it is not feasible to replace conventional cars with electrical powered vehicles today. The way of transportation in the cities has to be analyzed and modified in order to satisfy people’s needs in big urban areas, where electrical concepts show the highest potential. Conventional cars are made for multiple purposes and are not optimized for transportation in metropolitan areas. Current research among commuters shows for example, that mostly only 1 to 2 persons are seated in one car. In Germany every car is according to [7] equipped with 1,33 persons.

In addition the available storage space, as well as the different systems, mainly aimed to increase the comfort, is rarely used. This leads to the following requirements for urban mobility concepts:

- Space for 1 to 2 persons
- Compact measures
- Safety (less than a car, but much more than a motorcycle or a scooter)
- Weather protection capability
- Small storage space
- Low total costs

KEY TECHNOLOGIES
In order to reach these goals, different technologies have to be combined to create a lightweight, cost efficient and low emission transportation concept. In addition to an efficient electric engine as well as
appropriate battery systems, lightweight materials play an important role. The structural weight is directly correlated with the needed engine power as well as the battery size. Therefore, if weight can be saved in the structural components, additional weight can be saved using a smaller battery and engine.

Fig. 1 shows a short overview of important lightweight materials according to [8], where material properties, the density and the tensile strength are correlated with each other. In order to build a lightweight structure, materials with low density as well as good mechanical properties - high tensile and compressive strength, as well as high stiffness - are needed. In most technical applications, aluminum alloys, titanium alloys as well as fiber reinforced plastics (FRP) are used. Despite their good properties, continuous FRP and especially CRFP (carbon reinforced plastics) are mainly used for high performance aerospace and automotive components as well as consumer goods due to the high material and manufacturing costs.

This is the reason, why short fiber reinforced plastics are used and locally replaced by other materials with higher mechanical properties. The injection molding process is defined to be the most cost effective manufacturing process today. Due to the high geometrical flexibility it allows the fabrication of all main structural parts. Furthermore, a high degree of integral architecture is used to minimize parts as well as assembly efforts. The combination of different parts and functions for creating an integral part with multiple functions is found to be one of the main key drivers to reduce weight and costs at the same time.

**E3W CONCEPT**

The E3W concept represents a new vehicle architecture with new material technology. It shows the applicability of lightweight design for affordable urban transportation concepts. Embedded in a research project, a completely new transportation concept is designed and developed. Special focus is given on manufacturing processes as well as strategies for mass production. Finally, two prototypes are built and tested to evaluate the applicability for daily use and to proof the concept.

**Homologation**

In order to develop a new transportation concept homologation aspects have to be taken into account. Each homologation class is defined by typical features such as motorization, geometric measures, wheel-concepts or weight [9]. Due to technical (geometric restrictions, engine concept, etc.) and legal issues (car registration, legislative rules, etc.) the L5e class is chosen for the described three-wheel concept, which combines the advantages of a two-wheeler with those of a four-wheeler. The advantage of the L5e homologation is less technical requirements than the M category, which applies for cars.

**Development and design process**

Starting from the described requirements above, a conceptual study is carried out combining technical as well as design aspects. As shown in Fig. 2a), different design sketches are made to define the shape and design as well as the technical feasibility and structural features of different transportation concepts. These sketches are used to derive technical concepts, which are further detailed and finally simulated. Fig. 2b) shows 3D models of main structural parts of the chosen chassis concept. It consists of a multi material floor structure (in the center of the exploded assembly drawing) and various shell structures. The primary joining method is adhesive bonding. In order to validate the developed chassis concept concerning usability and ergonomics, a special mockup is build, shown in Fig. 2c). To validate the driving performance a functional prototype is built and tested (see Fig. 7a).

![Fig. 1: Schematic comparison of important lightweight materials (according to [8])](image1)

![Fig. 2: E3W design and development process: a) design sketches, b) functional ergonomic mockup, c) kinematic prototype](image2)
Plastic chassis

As described before, one main part of the lightweight transportation concept is the plastic load carrying chassis. The global material used is PA6 GF50, which consists of a thermoplastic matrix with embedded short glass fibers. The reinforcement percentage is 50%.

In order to compensate the lower mechanical properties compared to metals or CFRP, large cross sections and hollow profiles are used. The architecture is quite different to a typical car body, as in this case the body is exterior, interior and load carrying structure in one piece. In order to minimize parts and to optimize production, the profiles are made of two parts, which are glued together. In some cases the use of PA6 GF50 is not suitable due to technical reasons and thus different materials are used. Fig. 3 and Fig. 4 show the main components of the chassis where Fig. 3 summarizes the main structures made of PA6 GF50. Fig. 4 shows the results of the local material optimization. Especially the floor unit gives a good example for the conceptual design. It consists of main load carrying longitudinal glass fiber reinforced (GFRP) pultrusion beams, which are combined with PA6 GF50 structures to create hollow chambers in order to meet e.g., crash requirements. A further local material-hybridization is used for seat fixation (steel alloy components).

Suspension concept

The suspension concept of the E3W strongly differs from conventional car suspension concepts. The single wheel at the back axis is connected to the chassis by a single swing arm and powered by a cardan shaft. The technology is adopted from two-wheel concepts and modified according to the present requirements. The front suspension concept is based upon a GFRP composite spring that also guides the wheel and serves as stabilizer. This leads to a so called McPherson axis concept [11].
EXPERIMENTAL TESTING

Complementary to the development, design and simulation process, experimental tests are carried out in order to validate results and to investigate ergonomic as well as car handling and driving behavior. Therefore different functional prototypes are build (see e.g., Fig. 2c) for an ergonomic mockup). The driving tests are carried out at an early development stage using a prototype as shown in Fig. 7a) to validate the kinematic concept. For the validation of the final driving behavior as well as the performance the final prototype is used (see Fig. 7b)). Additionally, usability tests are carried out to proof the interior concept, focusing on the most important aspects of everyday use for commuters as well as sensitivity studies are carried out to find an optimal layup concept.

CONCLUSION AND OUTLOOK

Sustainability and the reduction of emissions are currently in the public focus. Therefore multiple efforts are made in different industries to reach legal requirements and to develop future technologies. The E3W concept shows the potential of current and new lightweight technologies in the automotive context. This feasibility study of a new electric urban transportation concept mainly consists of structural plastic components. The main manufacturing process, injection molding, leads to low costs and simultaneously enables a high freedom of geometry and design. Moreover, only few different materials are used, which leads to efficient and simple recycling. The use of short fiber reinforcement hollow profiles with large cross sections allows a highly integrated design. Local material hybridization enables the connection of other structural parts with an increase in stiffness at the same time. Experimental testing proofed excellent driving and handling performance of the vehicle. Driving tests in urban areas also showed the advantages of this concept compared to conventional cars by means of everyday use. Furthermore a business model for mass production was developed in order to show the suitability of this development for mass production.

Therefore, the E3W concept is a good starting point for future developments and efforts to reduce emission and to build sustainable urban transportation systems.

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REFERENCES