# EV 3.0: A Designg driven Integrated Innovation on Rapid Charging Model BEV Mobility

**Miaosen GONG**, School of Design, Jiangnan University, miaosen.gong@foxmail.com
**Xiang ZHOU**, Jiangsu Duke New Energy Automobile Co., Ltd, 43790098@qq.com
**Qiao LIANG**, School of Design, Jiangnan University, liangqiao@jiangnan.edu.cn
**Juanfang XU**, School of Design, Jiangnan University, xjf@jiangnan.edu.cn

## Abstract

This submission reports a design-driven integrated innovation on EV mobility, EV 3.0, as a collaboration between design research institution and a small BEV company in China. The on-going project provides a novel vision and design strategies of Battery Electric Vehicle (BEV) and mobility and has achieved a key technological performance on rapid charging of BEV. The current situation of BEV Industry and their recharging patterns show a big gap of new energy mobility. Key issues of BEV and mobility are defined by analysis of users' need of mass market and a case study of a leading BEV. Usability of charging is identified as a bottleneck of BEV industry. Hence a new vision and scenario of rapid charging are defined, leading to respective design strategies and technological routines. With a long term investigation and iterative prototyping, an established prototype is developed and officially tested in the National Center of Supervision and Inspection on New Energy Motor Vehicle Products Quality in Shanghai. The test result indicates that the prototype has 431 km range in speed of 80km/h with only 15 minutes' recharging, which provides a valid routine to break bottleneck of BEV industry .

***Keywords:*** *Integrated innovation design; Sustainable mobility; Battery electric vehicle; Rapid charging;*

With pressing challenges of energy and environment, new energy mobility is widely proposed by main countries and international bodies as a key strategy of sustainable development. In China, new energy vehicle is defined as one of seven strategic emerging industries in "Energy-efficient and new energy vehicle industries development plan (2012-2020)"（China National Energy Administration 2012) to keep energy security and to reduce its carbon emissions, followed with a series of policies and plans to promote it in national and local levels. Battery Electric Vehicle (BEV) is regarded as a major promising industry in the field according to technological advancement and Chinese energy situation. Although China is becoming a leading country in BEV with governmental supports in industrial policy and planning, the entire current solution is still far from application for mass market (Liu, Wang &Ari 2014), particularly in personal consumption market. Given that, EV 3.0 project reported in this paper aims to discover new opportunities of integrated innovation by collaboration between design agency and industries.

## Project definition

Previous research indicates the key factors constraining BEV industry are capacity of battery, economic cost, recharging infrastructure (Liu, Zhang & Liu 2014). Therefore, major industrial concerns focus on battery technologies with large scale investment on the one hand, and major policy recommendation is public recharging infrastructure construction. However, the overall situation of BEV industry hasn't progressed efficiently or sufficiently. Hence, EV 3.0 project doesn't stand on those key factors, instead it returns to user's potential needs in the perspective of human- centered design, to discover new opportunities and paths for breaking bottleneck.

EV 3.0 project recognizes that in the perspective of technology, BEV is not continuation of traditional vehicle, but a disruptive solution. hence, a design-driven innovative approach is employed to redefine problems, redesign scenarios and reshape mobility system. The project starts from user needs identification from three perspectives including usability, safety and economy in order to define the key challenges of marketing. According to the defined challenges, project investigates the industrial context in recharging models and a case study of a leading band to understand better the bottleneck of industry. Afterward, a new vision of BEV system is defined with multiple scenarios of recharging services and design strategy of BEV, which approaches to new ideas of technical innovation. furthermore, it goes with iterative process of design and prototyping to reach designing objective of defined vision.

## User needs identification

To understand user needs is fundamental for problem definition and concept generation. User research is well recognized as essential design research to investigate users' need. In practice, user research, particularly quantitative user research, might be rather effective when it supports projects of optimization design or incremental innovation than when it does radical innovation projects. In the field of BEV mobility, BEV and related services have appeared for decades while it's still tiny if looking at the entire market and industry. As a potentially promising industry with not-well prepared solutions, to develop a valid system in this sense is a disruptive innovation with discontinuation of traditional vehicle and mobility. Therefore, average user research may easily enter detailed level of observation and finding, therefore, we need a designerly way of user needs investigation to look out a big picture of BEV and mobility.

On the foundation of comprehensive research on EV industries, markets and users, we look into the basic needs of general users of mass-market. Both traditional or BEV mobility, their values to user are near to each other. Hence, three perspectives include usability, safety and economy are defined to investigate the basic needs of potential users of BEV.

(1) Usability: key factors of usability of BEV are range, accessibility of recharging service and recharging time. With technological advancement in battery and lightweight, range is largely improved and reaches general range of traditional vehicles. While there are still obvious gaps in accessibility and time of recharging.

(2) Safety: besides of normal safe factors of vehicle, the safety of BEV mainly depends on that of battery. With progress of battery, Battery Management System (BMS) and battery pack, the safety of BEV is also enhanced well with relatively high risky perception.

(3) Economy: comparing to traditional vehicle, BEVs have huge economic advantages both in using cost of energy and production cost. The major part of price of BEV are cost of battery. Under the governmental tax and subsidy policy for EV battery industry, the price of BEV largely decreased.

Therefore, usability of BEV is proposed as a bottleneck of BEV industry. Current recharging system and model could not meet the basic needs of potential customers. In another word, current BEV and recharging system are not a real valid solution. How to increase the efficient of recharging and decrease the charging time to fit the psychological perception and behavior habits are key challenges of BEV mass-scale development.

## Context of BEV industry

Since recharging system is recognized as weakness of BEV industry, it's important to understand well current situation of it. In global, Chinese sales of new energy vehicles in 2016 are 507,000 in total, including 409,000 all-electric vehicles and 98,000 plug-in hybrid vehicles (Liu 2017). China is the largest country whose stock of new energy vehicles with cumulative sales of more than 951,000 units until December 2016. These figures include passenger cars and heavy-duty commercial vehicles both. As matter of fact, fast development of BEV industry in China is largely driven by government policy with public subsidy (Wang, Liu &Ari 2014). Moreover, the majority of purchased BEVs are distributed in public fields like Buses, Taxi or sanitation trucks, where the recharging system and service can be organized according to respective specific service systems.

### Current recharging models

Either in public sectors or personal markets, recharging system and service are fundamental infrastructure for application of BEV. As an emerging industry, there are several models in parallel exploration, mainly including normal plug-in model, battery swap model and fast recharging model.

(1) Normal plug-in model: it's a normal model for average passenger cars. It's a long time recharging for 8-10 hours by low power input in average environment like houses or communities. The system solution is relatively simple, solid and economic. The model fits the scenario of commuting.
(2) Battery swap model: This model shifts recharging time and place out of BEV by swapping battery. It's a centralized system with united management for a quick solution for car. It requires a large scale infrastructure, particular support of grid and high compatibility of standards. This model usually fits public or commercial mobility systems like bus and taxi.
(3) Fast charging model: This model employs high power input to recharge in 20 mins-2 hours in public recharging stations. The solution is not well prepared with negative impact to grid. The model mainly fits the scenarios of emergent recharging.

So far, there are different strength and weakness respectively between three models. From the viewpoints of user needs, fast charging model would be the best. While the technological solutions are not solid and it only can be the supplement of other two. Normal plug-in model obviously couldn't meet the user need comparing to traditional vehicle. Although tree models have some complimentary advantages, they couldn't provide valid system and service for large-scale of BEV in future. The market and industry call for a new scenario and solution of recharging system.

### A case study

Although BEV solution hasn't met the basic need of mass market users, major automobile companies and new energy vehicle companies all over the world continue launching new BEV with progress advancement to test and incubate personal consumption market. Tesla targets high-end market by rising up driving performance, safety, smart digital system and user experiences. It employs creative and strong strategy in branding and marketing to cover the limitation of recharging. Instead, some Chinese companies like BYD focuses on middle range market. With advantage of battery technologies and policy support, it quickly opens fresh market with average solution.

Given that, as defined above, the usability of recharging system and service is bottleneck of BEV industry. A serious case study was done with Tesla as a leading company in BEV. It continues having advancement in recharging solutions including normal plug-in model at home and fast recharging model in Tesla super-charging station. In the later solution, the recharging time could be reduced around 1 hour. The designing highlights of Model_S[1] include: (1) Integrating battery pack into chassis optimizes structure and stability, and utilizing aluminum alloy materials for chassis reaches better light weight design. (2) Advanced BMS and large-scale battery pack consisting of Panosonic NCR 18650 battery balance factors between stability, capacity, recharging speed and economy. (3) A complicated temperature control system of battery pack protects temperature sensitive battery.

What we learned from deep study of Tesla Model_S: (1) among power batteries, NCR 18650 Ternary Li-ion Battery has performance of fast recharging, with potential for faster recharging system if temperature is better controlled; (2) In fast recharging solution, high power generates large quantity of heat. Hence, heat management and temperature control are a key difficulty of battery pack; (3) aluminum alloy material has good quality in strength, density and thermal conductivity and could potentially play unique role in safety, lightweight and temperature management of BEV. Those finding from case study may support a new vision.

## New vision, scenarios and strategies

### A new designing vision

Since usability of BEV, particularly recharging time are the key factor of user need in mass market, how much time of recharging is acceptable? Tesla develops a fast recharging model with a specific network of super-charging stations. However, one hour or even half an hour recharging time are still far from the psychological perception and behavior habit of users comparing to traditional car. Although in the perspective of key technologies, BEV is a discontinuation of gasoline car, in the perspective of users, they are two similar transportation tools with same using values in everyday life. Hence, if recharging time of BEV could be near to the time of refueling time of gasoline, BEV industry would have sound conditions for mass market and large scale development. According to basic user

[1] http://www.teslamotors.com

needs and assumption of recharging, a new vison of EV 3.0, “Rapid Charging Model (RCM)” is defined: (1) Range more than 350 km; (2) Recharging in 15 minutes; (3) Centralized charging station network; (4) Solid battery safety. In this novel vision, users could recharge their BEV as convenient as gasoline car refueling. People may easily shift the using scenarios of gasoline car to BEV. In the vision of RCM, there are two clusters of key factors. One cluster focuses on charging infrastructure and service; another one focuses on BEV, including range, charging time and battery safety.

## Scenarios building of charging services

Since RCM model is near to gasoline refueling in user perspective, the scenario of rapid charging station could be also near to the gasoline station. However, the gasoline station network has been built for decades or hundreds of years so that the density of distribution is sufficient for everyday life use. To balance the diffusion of BEV and rapid charging station network, alternative scenarios are proposed in the vision of EV 3.0.

(1) Super-charging station. It’s a typical centralized station like gasoline station with high power input and efficient recharging in 15 minutes, located in urban and high way (Figure 1). Users may would have similar experience as well. Even so, in the front stage, there is a unique parking system with rapid charging function to increase the capacity of charging vehicle. In backstage, there is big storing battery pack as power bank, which inputs electric power during peak valley at night and outputs during recharging in day-time as a distributed power network.

Figure 1: Scenario of super-charging station (PSSD2015)

(2) Mobile-charging station. It’s a mobilized super-charging station by adapting into a power station truck (Figure 2). It has less capacity and power. While it could move to almost any places according to situation of needs. It’s a dynamic service as an effective supplement of super-charging station network particularly when it’s not sufficient or some emergent situations.


Figure 2: Scenario of mobile-charging station (PSSD2015)

(3) Normal plug-in stand. As at beginning, centralized station network would be not enough for a long-term, utilizing the normal household or public charging stand is also positive supplement, especially for commuters (Figure 3).


Figure 3: Scenario of normal plug-in stand (PSSD2015)

## A new design strategy of BEV

As defined in previous discussion, related factors of rapid charging system include lightweight, battery capacity, temperature control and strength of battery pack. Among them, range mainly depends on battery capacity and lightweight; charging time mainly depends on battery capacity and temperature control; and battery safety mainly depends on temperature control and strength of pack (Figure 4). Therefore, the key factors of RCM are lightweight, temperature control and strength, which exactly matching the unique attributes of aluminum alloy in density, thermal conductivity and strength.

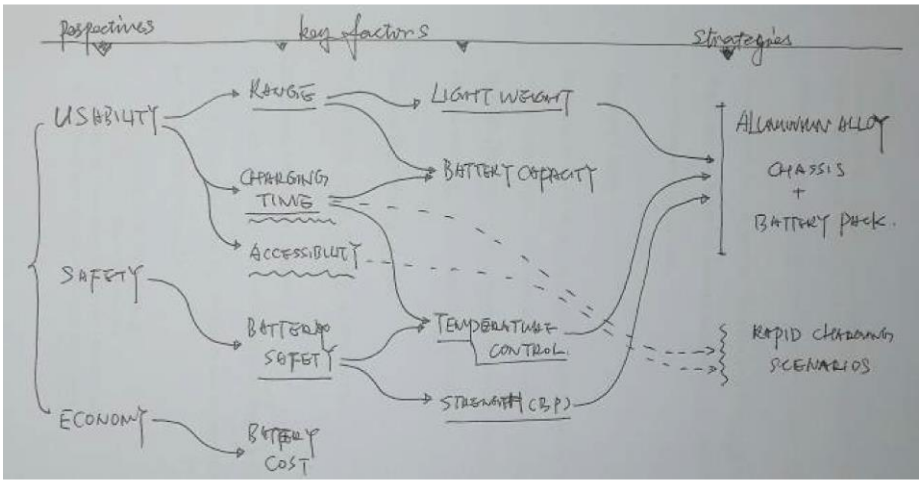
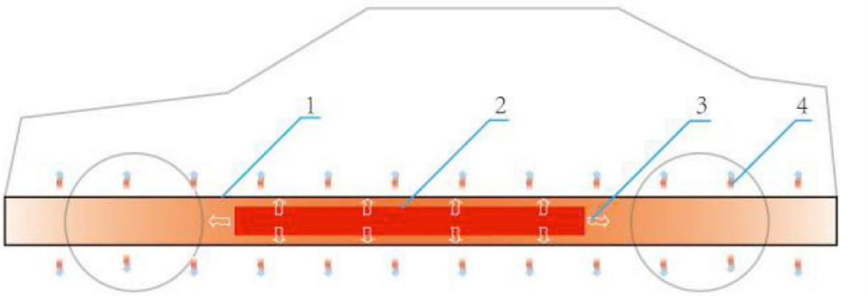


Figure 4: key factors and strategies of RCM

Therefore, a new strategy of integrated innovation is defined: to build an integrative chassis platform with battery pack by aluminum alloy material and process to effect key factors by its natural attributes and advantages. Finally, a passive heat balance system is created to reach the temperature control (Figure 5).




1 Chassis；2 Battery Pack；3 heat conduction；4 heat emission
Figure 5：passive heat balance system of super chassis platform

## Prototyping and a new concept

According the new vision of EV 3.0 and defined strategy of BEV, a long-term research and development of rapid-charging oriented BEV has been done by jointed project team. After iteration of functional prototyping (Figure 6), finally the jointed project team developed a prototype reaching the objective criteria of RCM vision. The final prototype has an integrative chassis platform with integrated battery pack as the key of innovation. Corresponding BMS is also developed and other parts of vehicle are purchased from third parties. In addition, a specified charging stand for RCM is also developed for its test.

Figure 6: one of functional prototype of EV 3.0

The prototype vehicle of EV 3.0 was tested by the National Center of Supervision and Inspection on New Energy Motor Vehicle Products Quality (www.smvic.com.cn) in Shanghai. The test is conducted as 80km/h speed method on the drum to provide the test data according to GB/T18386-2005, EV energy consumption rates and range test methods. The results indicate: (1) Curb weight (kg): 1750; (2) Charging time: 15 minutes; (3) Charging Quantity(kwh): 65.2; (4) Range (km): 431 (Figure 7-8). The test result reach major key objectives of new vision of EV 3.0.

Report NO.: SW1500033N000

# Test Report

Range and energy consumption of electric car

Sample Name: Pure electric cars

Sample Model: Gongjue EV 3.0

Customer: Jiangsu Gongjue New Energy Car Co., LTD.

Issued Date: 2015.4.10

**Shanghai Motor Vehicle Inspection Center**

**National Center of Supervision and Inspection on New Energy Motor Vehicle Product Quality**

Figure 7: test report of EV 3.0 car prototype_a

National Center of Supervision and Inspection on New Energy Motor Vehicle Product Quality

**Report NO.:** SW1500033N000

**Test Report**

2 Page of 2Pages

1. Test instructions

According to the entrust between Jiangsu Gongjue New Energy Car Co., LTD. and SMVIC, the test is conducted as 80km/h speed method on the drum to provide the test data.

2. Test data

| Test program | Test result | Remark |
|---|---|---|
| Driving distance(km) | 431 | 80km/h speed method |
| Charging Quantity(kwh) | 65.2 | Charging time: 15min |
| Energy Consumption(Wh/km) | 151.28 | - |

3. Test time and location

2015.4.9. In SMVIC

4. Sample data

| | |
|---|---|
| Vehicle type | M1 |
| Motor model and manufactory | JEEMC01002B Juyi Company |
| Curb weight (kg) | 1750 |
| Max weight (kg) | 2010 |
| Motor type | Permanent magnet synchronous |
| Motor position and arrangement | Front arrangement and front drive |
| Power rating and the corresponding rotational speed | 13kw /3000rpm |
| Battery model and manufactory | 18650/Gongjue |
| Battery type | The ternary lithium battery |
| Battery voltage/capacity (V/Ah) | 370V /179.8Ah |
| Number of shaft | 2 |
| Tire model | 175/65 R14 |

5. Test photo

Figure 8: test report of EV 3.0 car prototype_b

On the foundation of RCM system and prototype, a new BEV concept is proposed as a concept design toward a specific target to explore new possibility of final product. The defined target user is core family of urban middle class, and the define BEV is a SUV for their everyday life, as a third space between home and companies or schools with multiple functions and rich user experiences (Figure 9). Comparing to traditional vehicle, the new concept indicates a simpler structure and more flexible spaces depending on the integrated chassis platform of EV 3.0 (Figure 10), which leads a new proposal of car exterior and interior (Figure 11-12).

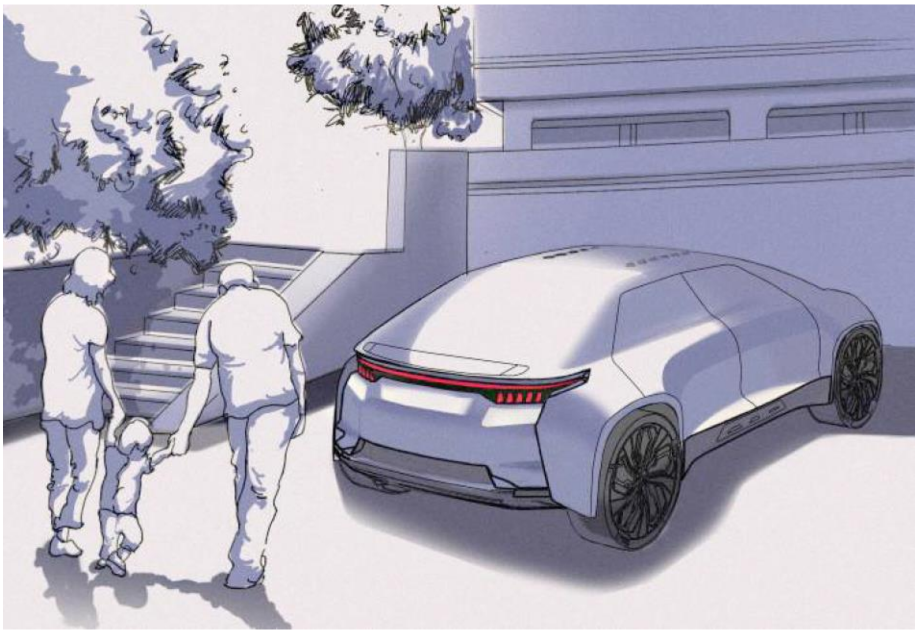


Figure 9: Scenario of new BEV concept (GFP 2017)

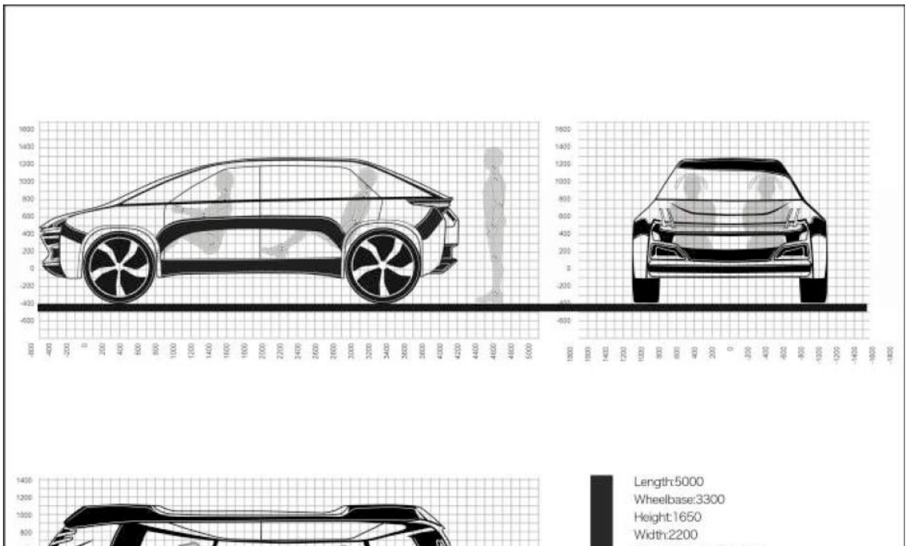



Figure 10: Shape and space of new BEV concept (GFP 2017)

Figure 11: Exterior design of new BEV concept (GFP 2017)

Figure 12: Interior design of new BEV concept (GFP 2017)

## Conclusion

EV 3.0 regards the BEV is a discontinuation of gasoline car and redefine the vision of BEV mobility according the basic user needs as a big picture. A car prototype with breakthrough innovation were developed to reach the new vision of RCM. As an on-going collaborative project, there are lot to be done for complete systematic solution and further car design and development of BEV, while the current results and outcomes so far is already valid to envision new possibility of BEV mobility and create new industrial opportunities. EV 3.0 is a design-driven integrated innovation. Facing complex challenges of BEV mobility, the collaborative project team employs interdisciplinary and human-centered approach to reshape the problems and integrate different opportunities for disruptive innovation.

## Acknowledgement

The project reported in this paper is a long term collaboration between DESIS Lab of Jiangnan University and Jiangsu Duke New Energy Automobile Co., Ltd with strategic partnership. Thanks to all participants of two partners and other stakeholders. It largely depends on a long exploration on sustainable and EV mobility in DESIS lab as one of main research tracks. Thanks to all colleagues, students, visiting professors and guess professors who involved into related research and teaching activities. The project also had advices and supports from China Academy of Engineering major consulting project “Innovative Design Developing Strategy” (2013-2016) and National Social Science Foundation major project “Green Design and Sustainable Development” (13ZD03).

## References

China National Energy Administration (2012). Energy-efficient and new energy vehicle industries development plan (2012-2020). Retrieved in http://www.nea.gov.cn/2012-07/10/c_131705726.htm

Liu y., Wang J & Ari K (2014). EV Demonstration Policy and Business Model Innovation: Global Experiences and China's Practices. *China Soft Science*, 12, 1-16.

Liu W., Zhang L., Liu Z. & etc. (2014). A Development Pattern Argumentation Method for Battery Electric Vehicles in Cities. *Automation of Electric Power System*, 24, 34-40.

Liu W (2017). China Auto Association: 2016 new energy vehicle production and sales were over 500,000, an increase of about 50%. Retrieved from www.D1EV.com.

Wang J., Liu y & Ari K (2012). Policies and Effects of "Ten Cities One Thousand New Energy Vehicles" Project. *Scientific Decision Making*, 12, 1-14.

## Author Biography

### Miaosen GONG

Dr. Miaosen Gong is an Associate Professor of School of Design, Jiangnan University, where he is the founder DESIS Lab_JU and and member of international coordination committee of DESIS association. Before, he obtained his PhD degree in design at Politecnico di Milano (associated with MIT). His research interests focus on strategic design for sustainability and service design for social innovation, innovation design, particularly in the fields of active welfare and public service, EV mobility and smart city, food& agriculture, health and elderly, with ongoing projects including Keyihui social lab, EV 3.0 and Wangjing Beishu organic farm.

### Xiang ZHOU

Mr. Xiang Zhou is chairman and chief designer of Jiangsu Duke New Energy Automobile Co., Ltd. He is also board member of Jiangsu Industrial Design Association. He graduated in industrial design of school of design, Jiangnan University. After working in car industries for ten years with rich design experiences, he founded Duke to develop in EV industry in 2011. With a new vision, he leads to develop the project EV 3.0 with breakthrough innovation in charging in collaboration with Jiangnan University.

### Qiao LIANG

Dr. Qiao Liang is a lecturer of School of Design, Jiangnan University. He got his PhD degree in design from Hunan University, when he was also member of “State Key

Laboratory of Advanced Design and Manufacturing for Vehicle Body". Sponsored by the China Scholarship Council, he spent one year at the Virtual Prototyping and Reverse Modeling Lab of Politecnico di Milano. His research mainly focuses on transportation system integrated design, especially styling feature, user emotion and behavior, multi-modal interaction and integrated design.

Juanfang XU

Dr. Juanfang Xu is an Associate Professor of School of Design, Jiangnan University. She obtained her PhD degree of digital Art and Design in Zhejiang University. Her research interests focus on computer-aided design and interaction design, mainly in the fields of healthcare and elderly living, car interface design and other kinds of product innovation.