

# Electric Mobility & the Urban Environment; the Schiphol Case

Sacha Silvester<sup>1</sup>, Satish Beella<sup>1</sup>, Arjan van Timmeren<sup>2</sup>, Pael Bauer<sup>3</sup>, Jaco Quist<sup>4</sup> and  
Stephan van Dijk<sup>5</sup>

<sup>1</sup>Faculty of Industrial Design Engineering

<sup>2</sup>Faculty of Architecture

<sup>3</sup>Faculty of Electrical Engineering

<sup>4</sup>Faculty of Technology Business and Management

Delft University of Technology, Delft

The Netherlands

[S.Silvester@tudelft.nl](mailto:S.Silvester@tudelft.nl)

tel. 0031.614015467

## Abstract

The introduction of electric mobility is one of the promising options to create a more sustainable mobility system for the future. Electric vehicles offer the promise of major reductions in local CO<sub>2</sub>, NO<sub>x</sub> and particulate emissions. In addition, electric vehicles are silent, easy to service and have high 'well-to-wheel' energy efficiency. However, the introduction of electric vehicles into society also poses several important challenges. Current electric vehicle technologies have limitations with respect to ease of use, driving range, and time-to-charge, and are relatively expensive. Moreover, the use of electric vehicles requires an adequate charging and electric grid infrastructure, as well as dedicated solutions for vehicle charging and storage that are optimally integrated into the built environment.

In this paper the results are presented of a 'design inclusive research' project for the introduction of electric vehicles in the urban environment. Researchers & designers from architecture, industrial design, electrical engineering and technology assessment were involved.

Amsterdam Airport Schiphol was taken as a challenging case. The Schiphol Group has the ambition to develop its properties and business park areas in a more sustainable and socially responsible way. Electric mobility is therefore one of the options to consider. The results show that it is possible to create a multifunctional, sustainable and comfortable urban area in which the electric mobility is very well integrated. It even can be stated that the sustainable urban development is becoming more feasible by the clever combination of renewable

energy, electricity grid design, inductive Park&Charge and customized electric vehicle services.

### **Keywords**

*Electric mobility, urban environment, .*

### **1. Introduction**

Mobility is a crucial part of daily life. It enables people to overcome the distance that separates their homes from the places where they work, learn, recreate, seek care, do business, or interact with family and friends. Businesses are also heavily dependent on mobility to overcome the distances that separate them from their suppliers, markets, and employees. However, when implemented at a large scale, mobility has a number of negative repercussions: congestion, particulate pollution, greenhouse gas emissions, noise, and accidents, to name a few. Another concern is that the world's current mobility systems rely almost exclusively on a single, limited source of non-renewable energy — petroleum.

The challenge, that society as a whole faces, is the design, development, and implementation of mobility systems that are more efficient, more equitable and less disruptive, both socially and environmentally (WBCSD, 2004).

The transition from conventional mobility technologies towards a situation in which electric vehicles (EVs) play a leading role is one of the most promising opportunities for achieving a sustainable mobility system. A large-scale introduction of electric vehicles has a variety of benefits, including higher 'Well-to-Wheel' efficiencies, the mitigation of local greenhouse gas emissions, particulate pollution, and noise, and increased support for renewable energy production. Moreover, electric vehicle batteries may provide auxiliary storage capacity for the electricity grid, further reinforcing the integration of renewable energy conversion technologies in the national electrical grid.

Past efforts to introduce electric mobility to the general public have struggled to transcend the niche markets that EVs have historically occupied. This is because the complexity associated with the widespread deployment of electric mobility necessitates a radical transition process, which draws upon specific knowledge of consumer behaviour as related to the use of products and services, as well as the anticipated trajectory of vehicle technologies. Infrastructures must be developed for the physical, as well as for the information and communication domains. To be successful in integrating electric mobility into

our built environment, synergetic research and innovation processes must take place; these form the backbone of this research project (Silvester, 2010). In this paper the project and its results are summarized.

This research falls within the context of the DIEMIGO project, which aims to advance the integration of electric mobility into the built environment. The TRANSUMO (Transition to Sustainable Mobility) program (Transumo, 2009) – a research program subsidised by the national government to improve the knowledge infrastructure of the Netherlands – has shown direct interest in the DIEMIGO project.

This project addresses a number of aspects associated with the transition toward electric mobility, including system innovation, supportive infrastructure, built environment, and vehicle products and services.

### **System Innovation**

The foreseen complexity and impact of the transition towards electrical mobility elicits the term ‘system innovation’. System innovation can be defined as a combination of technological, organizational, and cultural changes that result in a vastly different approach to the performance of familiar tasks. This project strives to develop a new understanding of mobility in relation to urban infrastructure. In doing this, several research methods can be utilized, including ‘backcasting’ (Quist, 2007), ‘visioning’, and the development of ‘design-orienting scenarios’ (van Notten et al., 2003, Manzini, 2008). The development of a method to cope with this complex ‘design’ process will be one of main objectives of this project.

### **Infrastructure**

The creation of supportive and reliable vehicle charging infrastructures is vital to the mass-deployment of electric mobility. Contemporary energy infrastructure is not yet suited to host large amounts of electrical vehicles (Hatton, 2009). Also, the ICT infrastructure necessary to manage the vehicle charging process has not yet been established. It is apparent that the semi-permanent incorporation of vehicle batteries into the electrical grid in the form of vehicle-to-grid interaction can improve the operational efficiency of the energy distribution system; the integration of this technology must be handled with care and ingenuity.

Simple, context-sensitive infrastructural systems will be necessary to support user acceptance and the smooth deployment of electric vehicles. The integration of the electrical

grid and ICT infrastructures, the designation of the charging speed, and the design of interfaces that support the location of charging stations and the charging, payment, and communication processes are to be addressed.

### **Built Environment**

Architects and urban designers must address the integration of charging infrastructure into the contemporary urban fabric. These designers may consider the positive effect that reduced noise and air pollution will have on the built environment. They may also consider the specification of land uses that are conducive to electric mobility, the coupling of vehicle charging with local renewable energy generation, and the design of parking facilities equipped with charging amenities.

### **Vehicle Product & Service Design**

The notion of well-functioning electric vehicles for public transport is a familiar one. In the near future, personal vehicles such as scooters, motorcycles, cars, and trucks will also undergo the process of electrification. The design of this new generation of vehicles must account for distinct changes in the interaction that takes place between users and vehicles, as well as that which takes place between vehicles and transport infrastructure. Designers of these future mobility concepts must also reflect on the influence of social and cultural trends on mobility patterns.

## **2. Research Structure & Questions**

This research will ease the challenges that society now faces in the mobility domain, as well as contribute to the generation of fundamentally new scientific knowledge. The epistemological aim of this programme is to contribute to the development of scientific knowledge through 'design inclusive research'. The goal of including design into the research process is to create new opportunities for generating new knowledge, which cannot be derived another way or can be obtained more effectively (Horvath, 2008). Design inclusive research is combining analytic research methods with synthetic/constructive design methods.

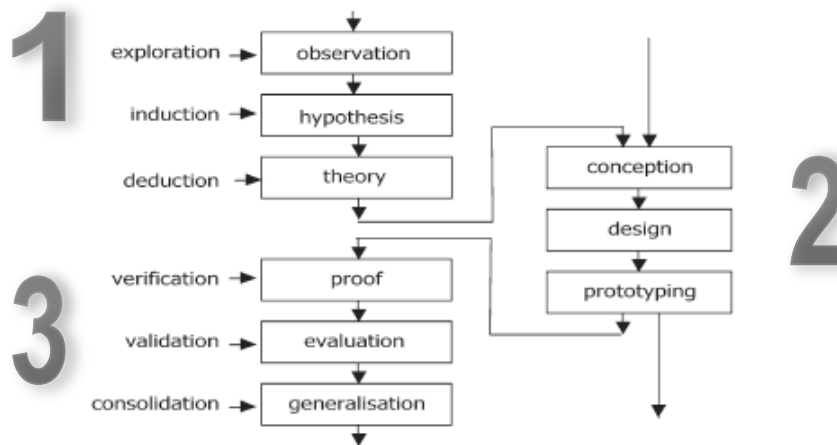


Fig 1. Design Inclusive Research. Left the research steps and right the design steps. (Horvath, 2008)

The process of design inclusive research is composed of three phases: the phase of explorative research actions, the phase of creative design actions and the phase of evaluative research actions. In the first phase, the existing knowledge and new developments about a specific phenomenon are analysed and the specific research questions and design problems are formulated. After the design phase, the third evaluative phase encompasses the verification of the hypothesis and the validation of the research and design methods and findings.

The main research question of the DIEMIGO-project is:

**‘How to integrate electric vehicles into urban and local energy infrastructures to improve large-scale adoption in 2020-2030?’**

The DIEMIGO-project is structured according to the three phases of the design inclusive research approach. The main research question is split-up in the following three sub-questions that represent the explorative, creative and evaluative phases:

- i. What are the challenges and requirements?
  - a. What are the mobility needs for 2030?
  - b. What local and decentralized energy sources could be integrated into the built environment?
  - c. What are the limitations of the grid for large scale EV introduction?
  - d. What are the challenges and requirements from an urban perspective?
  
- ii. What are the different solutions?
  - a. Which EV concepts fulfil the expected mobility needs?
  - b. Which urban and layout typologies fulfil the mobility, built environment and energy infrastructure needs?
  - c. Which are the interfaces most suited for the users, the EVs and the built environment?
  - d. What are the charging types, strategies and grid topologies?
  
- iii. What is the effectiveness?
  - a. Which solutions and technologies are feasible in what time scale?

- b. How it will affect the penetration of EVs and consumer acceptance?
- c. How and in which way can this project stimulate sustainability and a reduction of emissions?

### **3. Schiphol and The Grounds**

The 'design inclusive research' methodology mandates the use of appropriate case studies. The Schiphol Group is a strong partner for this project, as Schiphol Airport City is a complex location that serves as a pivotal point in the Dutch transport network. The Schiphol Group is currently devising a roadmap to illustrate the implementation of electric mobility (2008-2020) among its own fleet in close coordination with the neighbouring municipalities. The Schiphol Group considers electric mobility as an important opportunity for both its own fleet as well as for other public and private mobility streams flowing into and out of Schiphol Airport City. The Schiphol Group provided the research team with several options for locations to serve as case for this project. An assessment for location choice will be part of the project, in which the following criteria will be considered:

- Potential for combining the existing electric infrastructure (ProRail) with grid-to-vehicle and vehicle-to-grid facilities
- Potentially fast car-plane connections for EVs only
- Potentially fast car-inner city connections (e.g. for EVs only) by integrating a smart Transferium option next to the planned metro station
- Potential Landside/Airside combinational charging/services and energy exchange
- Potential EV car-share Network Hub with fast connections (highways A4, A9, and A10)
- Potential integration of risk strategy energy management system as a basis for a resilient energy system (integrating EVs, renewable energy, and development planning)
- Challenging complexity and potential interference with several planned developments.

The main objectives of the project are:

- To develop a preliminary methodology for planning, organizing and implementing large scale e-mobility and electric charging infrastructures. The 60Ha area (referred to as 'The Grounds') of Schiphol (and the roadmap developed by Econcern/Schiphol) will serve as a case; the strategy can be generalized in that it can be rolled out in other regions and locations (e.g. public and private fleet owners, centres that attract major mobility). This methodology is based on a single case (e.g. Schiphol) and will need further development after this project in order to improve validity and usability.

- To develop a design of a fast charging interface (including interfacing, grid connection, urban design implications, location choice, and implementation strategy) specifically for The Grounds; the strategy for setting up fast charge infrastructure can be applied to other regions/areas, fleet owners and contexts (e.g. grid characteristics).

The available time for the execution of this project has been limited because of the conclusion of the Transumo program in November 2009. Due to the fact that the project had to be finished within seven months, criteria were formulated together with representatives of The Schiphol Group in order to help focus the activities of the research and design team at TU Delft. These criteria guided the use of the restricted time as effectively and efficiently as possible. The following three statements explain the decision focus:

- The urban plan, its buildings, the charging infrastructure and the mobility solutions are stepping stones in the direction of a 'sustainable Schiphol' or 'CO<sub>2</sub> neutral Schiphol by 2012'.
- The infrastructure integration of the buildings and the mobility solutions are expected to be innovative and well supported by the latest developments. More important than the actual design manifestation are the requirements formulated to guide the generation of the design options.
- Potentially demonstrable elements of the scenarios in the near future or solutions that can already be applied are important in order to show the potential of the transition towards electric mobility for Schiphol Airport City. These spin-offs will motivate the various stakeholders, whose support is needed for the long-term transition process.

As a consequence of the limitations of this project – with respect to the available time – it was decided to focus on the first two phases of the 'design inclusive research' approach, namely the analysis phase and the conceptual phase. The third phase – the evaluative phase – is therefore beyond the scope of the project.

#### **4. Key results**

To assess the feasibility (in social, economic, technological, and policy terms) of existing electric mobility concepts an extensive technology assessment was executed at the beginning of the project, with the following main outcomes:

- The range of electric vehicles (EVs) is limited when compared to conventional cars. The state of current battery technology, although it is constantly improving, is one of the reasons for the limited usage of EVs. Significant technological breakthroughs are needed in order to develop an EV with a comparable range and an affordable price.
- Safety, modularity and compatibility will be the key aspects in establishing dynamic and long-term solutions for EV charging infrastructures. It is of great importance for successful implementation that these user-related aspects are taken into account when assessing EV technologies.
- The biggest bottleneck for the electrical infrastructure is achieving sufficient distribution capacity in the grid if EVs are concentrated in particular regions or locations and fast charged.
- The availability of full sized EVs for personal transport is still limited. However, with regard to market developments in the Netherlands, the numbers of hybrid EVs, professional market niches (e.g. on-site, public services, vans & small trucks), and electric bikes (pedelecs) and scooters are constantly growing.
- The environmental benefits of EVs are almost completely dependent on the type of energy production that is used to charge the battery.
- Changes in consumers' behaviour (e.g. using a second car, rental car or public transport) for longer trips might need certain adaptations and changes specific to their mode choices in order to use EVs and related infrastructure. This situation could be avoided with the implementation of technological solutions such as fast charging, battery swapping and range extenders.
- The higher purchasing price of an EV is a barrier for the buyer. As a result, there is need for and likelihood of different business models, such as battery leasing, which will develop in the early years of EVs.
- The vehicle-to-grid (V2G) option for exchanging electricity back and forth to the grid is viable if the EV charging and energy distribution markets are matched. In the United States, V2G services are very profitable for users if this match is sold as spinning reserves and grid regulation. However, these high value energy markets are presently non-existent in the Netherlands. Changes are required in the current Netherlands energy market in order to make V2G services economically viable.

To establish clear guidelines for the design of effective solutions for the integration of electric mobility in urban environments in the future, four different Design Orienting Scenarios (DOS)



for 2030 were developed. In addition to the existing Policy Oriented Scenarios (POS) of the CPB (CPB, 2004), which deal with the macro-scale of the socio-technical systems and present a variety of possible futures and facilitate political decisions, these scenarios are conceived as tools to be used in design processes. They are made of a variety of comparable visions, which are motivated and enriched with visible and tangible proposals. The driving forces for the scenarios are:

- CO2 neutral policy
- Zero emission regulation in urban areas
- Sustainable behaviour
- Focus on usership
- Technology developments, particularly ones related to batteries, fast charging and range extenders.

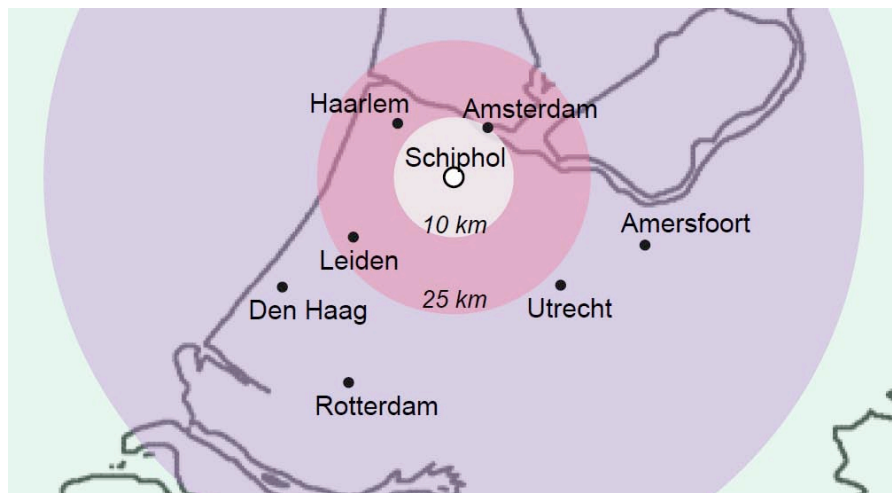


Fig 2. Central location of Schiphol

'Generation Eco-Geek' was the scenario chosen for further development, because it is the most conscious of the four developed scenarios with regard to sustainability (Fig 3). This scenario describes a world in which rapid technological development and minimalistic design principles are essential. Generation Eco-Geek marks a change in consumer behaviour: consumers exhibit a clear preference for value-based products and attention to detail. The Dutch society is CO<sub>2</sub> neutral and 70% of all Dutch cars are electric. Schiphol Airport also acts as a showroom for modern technological advancements. The airport is automated, space efficient and flexible, allowing it to remain compact and effective. This scenario is used to guide the development of the different design aspects, such as the urban profile and the modal split (mix of different travel modes) of The Grounds area of Schiphol.

To determine the operational context for future mobility systems at a specific location (i.e. The Grounds area), an **urban indicator tool** was developed. Based on the tool one can determine and simulate the type of activities and user groups in the area, the land usage for different functions such as working, parking, recreation, and local energy production, the number of electric vehicles and the anticipated vehicle usage.



Fig 3. Representation of the four scenarios, including 'Generation Eco-Geek'

Based on the results of the urban indicator model and the 'Generation Eco-Geek' scenario, an urban design for The Grounds was developed (Fig 4). The urban design demonstrates the creation of an ecological, comfortable, and silent business-science park and transfer point at The Grounds location that is able to host 9,400 electric vehicles every day (3300 HEVs and 6100 all EVs). The local renewable energy is mainly generated by photovoltaic systems that are integrated in the facades and rooftops of buildings. Green facades near the A4 highway and inner gardens with integrated algae production for energy production purposes are also an important part of the concept.



Fig 4. Aerial and detail views of the urban design layout for The Grounds

Based on the Generation Eco-Geek scenario and the urban design and designated urban functions, several novel electric mobility concepts have been developed that fulfil future user needs. Users, which include visitors, travellers, and employees of the business-science park, can select from a number of these electric mobility concepts (Fig 5). These concepts include:

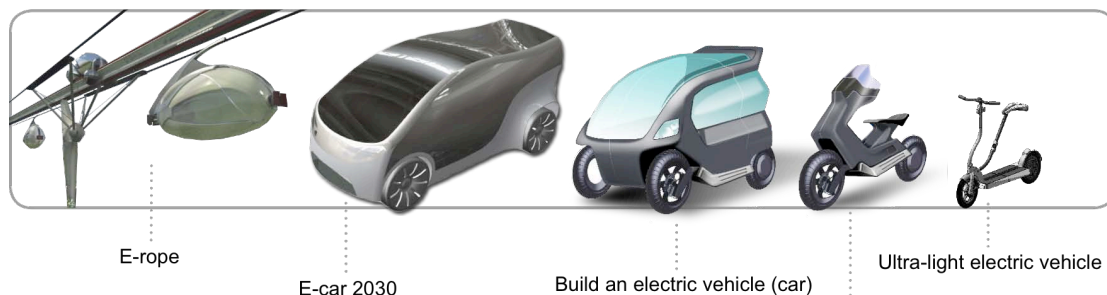


Fig 5. Various electric vehicles with specific and innovative functionalities

- The ultra-light EV is a small foldable, one-person electric powered vehicle used to form a link in chain mobility. It is suitable for short and medium range and in combination with other modes, such as with the E-car 2030 or public transport.
- The E-car 2030 is a space efficient four-wheel EV for two persons meant for airside and landside personal mobility, and it is optimized for automated parking and inductive charging. User-specific settings can be stored and uploaded in every available E-car.
- The E-rope is a special suspended vehicle that is based on a combination of both individual and collective components. It offers a frequent and comfortable bidirectional transport mode. The infrastructure needed for the E-rope is lighter and less rigid than a rail oriented solution.

- The Build-an-EV is a customizable vehicle developed to match individual needs and wishes. The concept is meant to serve different purposes with the help of standard components (two, three or four wheels, covered or open, variable ratio of person vs. luggage space, etc.)

The new generation electric vehicles are proposed along with an urban plan and building integrated supportive infrastructure for parking, charging, and vehicle assembly and distribution. There are many methods to charge EV batteries according to their different charging characteristics. Conductive charging technology is currently the most favoured, as it allows for the connection of EVs to an existing power supply with high efficiency and without the need for additional infrastructure. However, the recommended infrastructure to support the aforementioned mobility concepts makes use of induction charging technology. The use of induction charging increases the freedom and flexibility with which the charging infrastructure can be integrated into the built environment. Both *static* induction charging and *dynamic* (i.e., in-road and on the go) induction charging enable users to recharge their vehicles with ease at The Grounds (Fig 6).

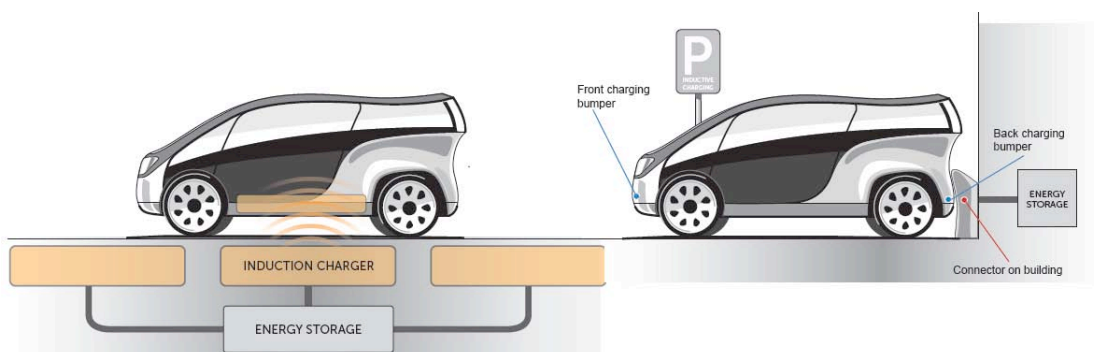


Fig 6. Dynamic Induction charging lane (left) and induction charging with the receptor located in the bumper (right)

The EV charging activities take place in the automated Park&Charge long-term garage, where the automated parking configuration and system result in a very dense parking solution (Fig 7). These garages – optimally oriented towards the sun - are equipped with photovoltaic facades and rooftops to locally generate electricity from solar energy.

The load profile modelling, the expected variation in the electrical load versus time, indicates that local solar power generation is matched to the anticipated electrical load at The

Grounds business-science park on weekdays, including the charging of electric vehicles. On weekends, there is an excess of locally produced solar power.



Fig 7. Schematic layouts of automatic parking at the Park&Charge garage and renewable charging facilities

Three different charging strategies are distinguished in this project: dumb, controlled and smart. In the case of 'Dumb' charging, no intelligence is added to the system and EVs are directly charged when connected to the grid. 'Controlled' charging means that EVs are charged during specific time-slots during the day. 'Smart' charging is also controlled and part of a smart network. A smart network is managing the grid load by enabling matching between demand and supply of electricity and the more effective integration of local renewable energy production (i.e. solar power).

Local electricity production with photovoltaic systems is economically feasible. Local renewable energy production enables the existing grid to cope with the intensified electricity flows resulting from the large-scale charging of electric vehicles. Thus there is no need to invest in strengthening the existing grid. Moreover, it is estimated that after the year 2020, the cost of grid electricity will be higher than solar production costs. The annual benefits from using solar energy will reach up to €1.3 million in the year 2030.

The V2G function of the Park&Charge garage is already economically attractive. With the assumption that the batteries of EV in the parking garages can always share the real-time bidding market, the annual revenue from the 6100 vehicles parked at The Grounds is estimated to be €0.19 million anno 2009.

To support the large-scale charging of electric vehicles and the integration of local renewable energy production different grid topologies are suggested; either a pure AC grid or a parallel AC-DC grid would suffice. A pure DC grid linked to the existing DC railroad grid could also be used, but this would require an update of the DC railroad grid, which is a 2601



km track equipped with 1.5 kV DC. The three proposed grid topologies do not have significant differences from an economic point of view.

Finally, vivid visualizations of the urban plan and the proposed mobility solutions are used for the communication of the project to external parties.

### **Recommendations**

The Schiphol Airport City location has been one of the first locations in the Netherlands to test and develop novel concepts and methods. To be able to generalise the findings and to validate the methodology, a number of diverse urban areas should also be researched, such as city centres and suburbs, and greenfield as well as brownfield situations.

The Technology Assessment executed within the framework of this project provides a general picture of the potential benefits of integrating electric mobility in the built environment. The specific consequences for Schiphol and its stakeholders resulting from the novel design choices made in this project – in terms of the environmental impact, the economic aspects and the identification of potential social, technical, and organizational barriers - have to be elaborated in greater depth. This assessment could not be accomplished within the available time span for the project.

A number of the future concepts presented in this project should be developed further. These include:

- The switch towards electric drive trains in the case of the 'Built-an-EV' appears promising with respect to the standardization of components and the development of universal EV-platforms. Customer acceptance of these highly customizable products is still unclear, as is the effect of customization when ownership of EVs is shifts towards usership.
- Fast induction charging, although currently used in domestic appliances, is still being developed for the induction charging of EVs. Aspects such as safety, efficiency, environmental impact, costs and usability should be thoroughly investigated.
- The automated Park&Charge garage, with its combined parking, charging and PV power generation, is one of the most interesting concepts resulting from this project. In the DIEMIGO case a large-scale version of the Park&Charge garage is presented. Research into a modular set-up for the Park&Charge garage is recommended. Smaller scale versions could be a very interesting option for sub- urban living areas.

Further research could also include alternative configurations (e.g. horizontal distribution) and the transformation of existing parking spaces to automated smart charging parking, or hybrid elaborations of both. In addition, research is recommended on the possibilities of converting existing (automated) parking garages into Park&Charge facilities.

- The smart grid integration needs to be investigated further for both charging and utilization of renewable energy sources, and its integration into buildings and building components, like building facades and parking area floors or ceilings.
- The lifetime of a battery system depends, among other factors, on the number of discharge/charge cycles. The incorporation of EV batteries as a buffer in the electricity grid (V2G) will lead to an increase in the number of cycles. This consequence can be a potential hindrance for the V2G option. Little is known about the effects on batteries that are integrated into V2G systems. Research on the effects of V2G on the lifetime of car battery systems and the environmental and economic consequences is recommended.

## **Methodology**

Although it was not possible within the timeframe of this research to include the evaluation phase along with the verification, validation and consolidation phases, the 'design inclusive research' approach as applied in this project looks very promising.

From a methodological point of view, some of the primary experiences are as follows:

- The ambition to actually design or develop a solution placed a great deal of pressure on the analysis phase. A clear formulation of a theoretical framework that could be converted into requirements for the design phase has got into hot water.
- Due to the time pressure, less stakeholder involvement was achieved than originally intended.
- Design has been a powerful means to generate synergy between the different disciplines (architecture, urbanism, industrial design, electrical engineering, technology assessment and innovation management).
- More cases have to be carried out in order to further develop the methodology for the large-scale implementation of electric mobility in the built environment.

## References

- CPB. 2004. *Netherlands Bureau for Economic Policy Analysis* [Online]. Available: [www.cpb.nl](http://www.cpb.nl) [Accessed].
- HATTON, C. E. 2009. *Charging Stations for Urban Settings. The design of a product platform for electric vehicle infrastructure in Dutch cities*. Master, Delft University of Technology.
- HORVATH, I. 2008. On the differences between research in design context and design inclusive research in the domain of industrial design engineering. *Journal of Design Research*, Vol. 7, 61-83.
- MANZINI, E. February, 2nd 2010 2008. Scenarios of sustainable ways of living. *Blog Ezio Manzini* [Online]. Available from: <http://www.sustainable-everyday.net/manzini/>.
- QUIST, J. 2007. *Backcasting for a sustainable future*, Delft, Delft University of Technology / Eburon Publishers.
- SILVESTER, S., BEELLA, S.K., TIMMEREN A. VAN, BAUER, P., QUIST, J.N., DIJK, S.J. VAN 2010. Integration of electric mobility into the built environment. Schiphol The Grounds. Delft.
- TRANSUMO. 2009. *Home page* [Online]. Available: <http://www.transumo.nl/NL/Home.aspx> [Accessed September 2009].
- VAN NOTTEN, P. W. F., ROTMANS, J., VAN ASSELT, M. B. A. & ROTHMAN, D. S. 2003. An updated scenario typology. *Futures*, 35, 423-443.
- WBCSD 2004. *Mobility 2030, meeting the challenges to sustainability* Geneva, World Business Council for Sustainable Development.