The impact of future cars on architectural design

Research paper

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Abstract

Cars demand accommodation in the build environment. The future cars are changing very fast, in the near future electric cars will replace the fossil fuel cars. The possibility for cars to drive autonomously is a hot topic, it's not the question any more If? it will be introduced in the mobility industry but the only question is When? This can totally change the application of design of use around the cars.

The objective of this research is to find key features that characterize the challenges and opportunities when designing a future building. To do this, research is conducted on the relationship between future cars and architecture.

Because the assumption is done that future cars will become electric and self-driving, after doing this research, in my opinion the main logical effects the future cars will have on architecture will be in the architectural design. In part 1 of the results, future solutions have been shown concerning parking and the arrival and departure. Also the contribution of the future cars by ways of V2G (Vehicle-To-Grid), as explained in part 2, will have a bonding effect regarding cars and buildings, because since the car is becoming part of the energy system has to be well integrated with the built environment.

There is more to be learned in the actual application of V2G and energy efficiency into the architectural design. Also more can be learned of analysing the use of the future cars. The technology in this field is rapidly developing, which makes this research topic an ongoing process.

Keywords: Future Architecture, Future Cars, V2G, Sustainability, Parking

1. Introduction

Background

This thematic research paper is part of the graduation project in the studio Architectural Engineering at the faculty of Architecture and the Built Environment at Delft University of Technology. The choice of the theme for this research is driven from a personal fascination for automotive design and future development. The objective of this graduation project is to develop a design in which the future electric car is integrated into a new building, where the future scenario of electric new mobility products become a part of the building and add to a high comfort for the user and the sustainability. This research results in key features that characterize the challenges and opportunities when designing a future building. The project location is Het Marineterrein in Amsterdam, an area near the city centre which was restricted because it used to be occupied by the naval establishment. The area is in transition to become public, so there is a big opportunity for new developments.

Problem statement

The relationship between cars and architecture is a long and complex one, as long indeed as the history of the car itself. From the very moment that self-powered vehicles took the streets of Europe and America in de last decade of the nineteenth century, architects and planners have been forced to confront the challenge of accommodating the car within the built environment (Wollen & Kerr, 2002, P. 315).

In my opinion cars or vehicles similar to cars will always stay part of the built environment, especially in big cities like Amsterdam. There are a lot of people that have extraordinary appreciation for their vehicles. Towards the future the vehicles are changing, which has consequences for the future design of buildings where people live and work.

Relevance

Cars demand accommodation in the build environment. The future cars are changing very fast, in the near future electric cars will replace the fossil fuel cars. The possibility for cars to drive autonomously is a hot topic, it’s not the question any more If? it will be introduced in the mobility industry but the only question is When? This can totally change the application of design of use around the cars.

Car manufacturers, researchers, governments and even architecture and urbanism companies are somehow involved with the subject of the self-driving cars. Car manufacturers like Tesla, Mercedes-Benz, Nissan and many more are showing their concepts of the self-driving cars they are working on and how they are going to be used. Tesla cars that are produced since October 2016 have full self-driving hardware (The Tesla Team, 2016). The functioning of self-driving is not available for the users yet but from the moment that it will be, they only will have to do a software update and the cars that are on the road today will be able to drive autonomously.

The municipality of Amsterdam is extensively researching the possibilities of the future mobility. The city is becoming more and more dense and the municipality is anticipating on ways to make Amsterdam become an accessible and safe but also viable city with clean air and attractive public spaces. Thereby they made an action plan for Smart Mobility in the near future (2016-2018), part of this plan and research are self-driving cars (Gemeente Amsterdam, 2016).

Research Question

Assuming that cars are changing in the near future, how will architecture integrate and adapt to it?

Sub questions:
- What will change in the future cars?
-What are the current integrations and adaptations towards cars in architecture?
-What are the demands of the future cars towards architecture?
-How can the future car improve the energy efficiency of buildings?

The research paper focuses on answering these questions. The results are divided in two parts. The first part concerns the architectural aspects and the second part explains the sustainability aspects. The results conclude in guidelines for the design project.

2. Methodology

This research paper is based on literature study, interviews and case study.

Literature study

Literature study is done in order to gain knowledge about future cars and how we are going to use them. Books, articles, websites and promotion campaigns of car manufacturers were very helpful to gain knowledge about current approaches and predictions for the future. However, there is very limited literature available that is specifically involving the integration and adaptation of the future cars in architecture. Most information about the change that the future cars will bring is on urban level, concerning infrastructure and sustainability.

Interviews

Interviews were done with people who gave me insight to more literature and knowledge about how it is done in the field at the moment. Besides interviews that were done, also videos of interviews were watched on the internet where leaders in the field of the future cars discussed their plans, e.g. interviews with Elon Musk the CEO of Tesla Motors which is one of the leaders in electric cars and development of self-driving cars.

Case study
The present and future developments of integration of the car in architecture and the sustainability of buildings gave insight to the research. Projects where V2G (Vehicle to grid) or self-driving cars already are functioning and future concepts of car manufacturers who show what they intend to produce in the future. This is helpful to understand what is done and what will be possible in the future, which raises new questions.

Self-Driving Cars
In 2005 the first "self-driving car" was born, a result of a project that was funded by Google. The Google Car became the leader in the autonomous vehicle field, with other leaders like Tesla, Mercedes, Audi, Apple, and Uber who are also determined to break into the market and make a change in the current automotive industry (Attias, 2017, P. 100). SAE International published a report with taxonomy for the automation levels of vehicles. In order to provide a common terminology for automated driving. They define six levels of automation (see figure 1) (SAE international, 2014). This research is based on the assumption that the future cars are in level 4 or 5 in automation. This means that the cars can perform autonomously with or without someone on board.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 1 Six levels of driving automation (SAE Internation, 2014)

3. Results

Part 1. Architecture

Cars and architecture

Frank Lloyd Wright's Robie House is a good example of how the use of the car had certain demands on architecture. This house is mostly known for its articulation of a symbolic relationship of a dwelling and the landscape where it is placed, but this was one of the first house designs to openly make provision for an integral car garage connected to a parking area (Wollen, Kerr, 2002, p. 318). This was clearly the way that the owners and their guests expected to arrive and depart, and the "front door" became a service entrance that was not even visible from the street side. The big arrow on the floor plan is where the cars enter from the street side and the small arrow is the "entrance door" (see figure 2).

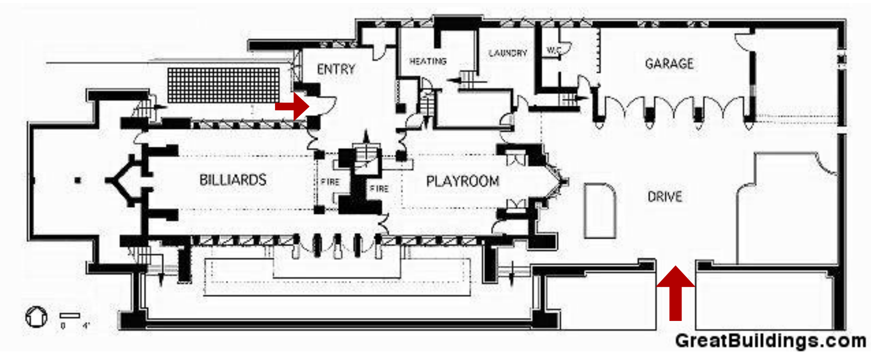

Figure 2 Floor plan Robie house (Greatbuildings.com)

Another example of the integration of the car in architectural design can be seen in Le Corbusier's Villa Savoye, 1929. The ground floor has a curved façade which is shaped by the turning circle of cars of that time, so the people entering the villa by car can easily drive into a the parking garage (see Figure 3) (Kroll, 2010). Of course in a lot of literature and designs Le Corbusier's connection to cars and architecture and urbanism has had a big role worldwide on the discourse and ideas following in time (Wollen, Kerr, 2002, p. 315).

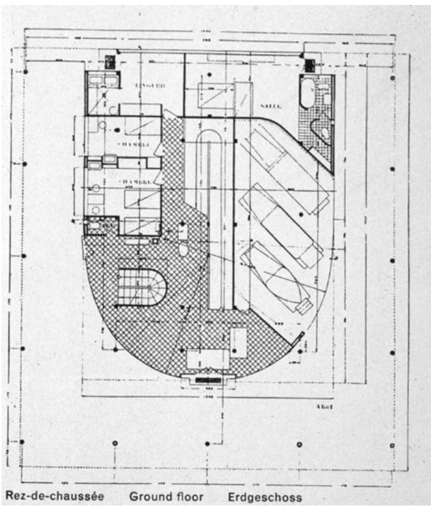

Figure 3 Floor plan Villa Savoye (Archdaily, 2010)

The previous examples show a clear integration of the use of the car into architecture in my opinion. This type of integration happened a century ago, but the principle now a day I s basically the same. People want to park their cars as close to the places they stay so they can access their cars any time they want. The two examples that are shown here are luxurious houses for the very rich of their era but nowadays we can see the same principle at even social housing flats all over the Netherlands where the main entrance of the buildings are, in many cases, oriented on the side where the parking lot is placed. But most cars we have today are running on fossil fuels so they just stand there and do nothing until someone decides to use them.

As the car gradually became in reach of the average person, especially in America, the car demanded a set of its own spaces, the freeway, the off-ramp and the parking lot (Bell, 2001, P. 120). These spaces have been developing all over the world and in dense areas like the big cities people had to look for creative solutions to house their cars. The parking spaces have become mostly involved with buildings. The parking garage has been the stepchild of building design for a long time. Designers had to deal with them in an economically efficient and functional way, which typically did not lead to the pleasant and safe spaces (Louter & Savooyen,2005, P. 7). Of course we see several developments to better parking spaces that are more safe and more pleasant.

Parking

Parking space, from an open space next to the road to a parking space that is part of a building and even total buildings built just for parking. In the Dutch book *'Parkeren op niveau: De parkeergarage als ontwerp opgave'* (Parking on Level: The parking garage as a design assignment) the following types of parking garages are distinguished:

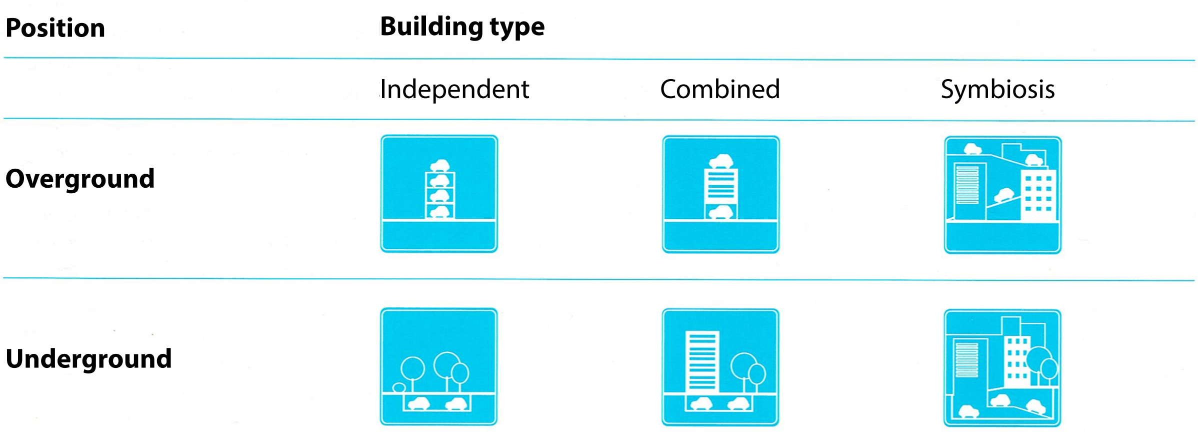

Figure 4 Parking garage typologies (Louter & Savooyen, 2005, P. 74)

Beside parking garages, we have the street parking spaces and outside parking lots. All of these types are basically used the same way, the driver parks the car, and then leaves the parked car to do the activities they have to do. In busy places you can lose a lot of time just searching for a free parking place. There are some solutions made by automated parking systems, where you drive your car in an elevator and leave your car, the parking systems brings your car somewhere in the building by elevator and when you come to pick it up it returns the car to the same place where you left it (see figure 5).

Figure 5 Automated Parking garage (Autostadt, n.d.)

But the future cars are self-driving which have a system that is able to park all by itself. The user can get out of the vehicle somewhere, the car leaves to go park itself and comes back by itself once the user needs it again. Before this technology, the space left between each vehicle in parking spaces is calculated with a side door opening to both sides so the user can get out of the car once it is parked. But now the user has already left the vehicle before the car is parking. This empty space needed for opening doors will not be needed anymore so we can save space in parking space (Attias, 2017, P. 101). An average parking space in a parking lot or garage should have a width of 2,5 meters, when cars are parked side by side according to the standards in NEN 2443 (NEN, 2013).

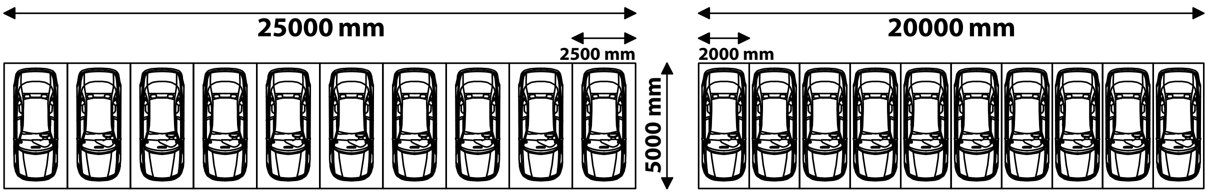

Figure 6 Example of space saving because cars will be able to park themselves, 20% less surface area per parking spot (Own illustration)

Figure 6 shows the space we would will be able to save when a car can park itself. Because the empty space for opening doors is not needed anymore which can save 20% of the space that car takes in today. This might look like a small impact on a scale of 10 cars as shown in this figure but on the large scale this means that a lot of space in dense areas can be saved for other functions.

Using the future car

Whether it is the digital distractions of the wired automobile, or the promise of autonomous parking systems. Automation of the cars was once the dream development of automotive interaction with the city, a push-button era that would make life faster, smoother and safer (Bell, 2001, P. 124). These dreams which could be seen in sci-fi movies, e.g. Minority Report (2002) and I, Robot (2004). But today we have several functioning and testing concept cars of car manufacturers that show the possible ways we could use the future cars. Daimler (Mercedes-Benz) shows a little sketch of how self-driving valet parking could be like (see figure 7).

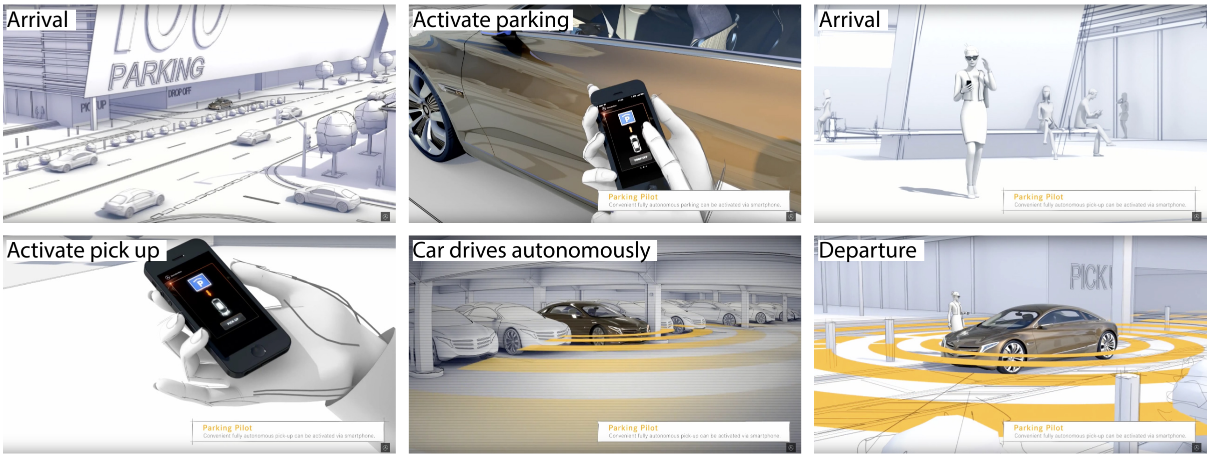

Figure 7 Screen grabs from a self-driving car concept in Daimler Parking Pilot video (Daimler, 2015)

Self-driving cars could be able to drop the user off at their destination and pick them up when they are leaving. The place where the user can get in or out of the car should be well designed, concerning safety and functionality and it should be integrated in urban design and architecture. We can learn a lot of the use of a driverless car by looking at people who have a chauffeur or use a valet parking service. Analysing this type of use can give insight about how and where to design drop off and pick up places. Also parking garages can be designed differently because only the cars go in inside, so it's not necessary to design them for people that walk inside the building, that need climate adjustments or walking and safety routs to escape the building via stairwells. Also because the cars will not have exhaust fumes anymore we can design special spaces inside buildings for those who have an extra ordinary appreciation for the cars they possess.

Part 2. Sustainability

The future self-driving cars are also assumed to be electric, which have large batteries. Electric vehicles are important players in government policy to reduce CO2 emissions from the transport sector and improve air quality. In the Netherlands, the amount of fully electric cars increases at a high pace, and the number of vehicles also increases the interest in electric driving (TNO, 2015, P. 2). The electric vehicles of today already have 30% less CO2 emission in comparison with the average petrol vehicles. This is in case the cars are charged lwith energy that is generated from grey energy (fossil fuels) sources (TNO, 2015, P. 20). This means that the emission of CO2 can be reduced dramatically, if all vehicles are becoming electric and the energy that is used to charge them is generated from sustainable sources the reduction can increase. This can result in a big improvement of the air quality, especially in dense areas like the city of Amsterdam. Along with this environmental benefit, there is also economic benefit. The electricity generated with PV (Photovoltaics) costs less than half of the current grid price per kWh (Mouli et al, 2016, P. 6).

The battery capacities of the cars are increasing in order to have a longer range of driving distance. These batteries are becoming so big that we do not need fully charged batteries at every moment. For example, the Tesla Model S has a Battery capacity of 100 kWh, which can be used to drive over 600 km on a full battery (Tesla Motors, n.d.). We do not need to drive 600 km every day. So we can use the battery for energy storage for the users of a building what in that case needs a connection between the car and the building. In collaboration with Nissan, Foster + Partners designed a future concept where the car battery could be used for energy storage which is generated by solar panels, so that the energy out of the car can be used when the solar panels are not generating energy (See figure 8) (Foster + Partners, 2016). This concept was presented March 2016 and in July 2016 a company in Utrecht, Netherlands, already made this happen (Lomboxnet, 2016). The steps that are taken in this field are moving very fast as technology is making a lot possible.

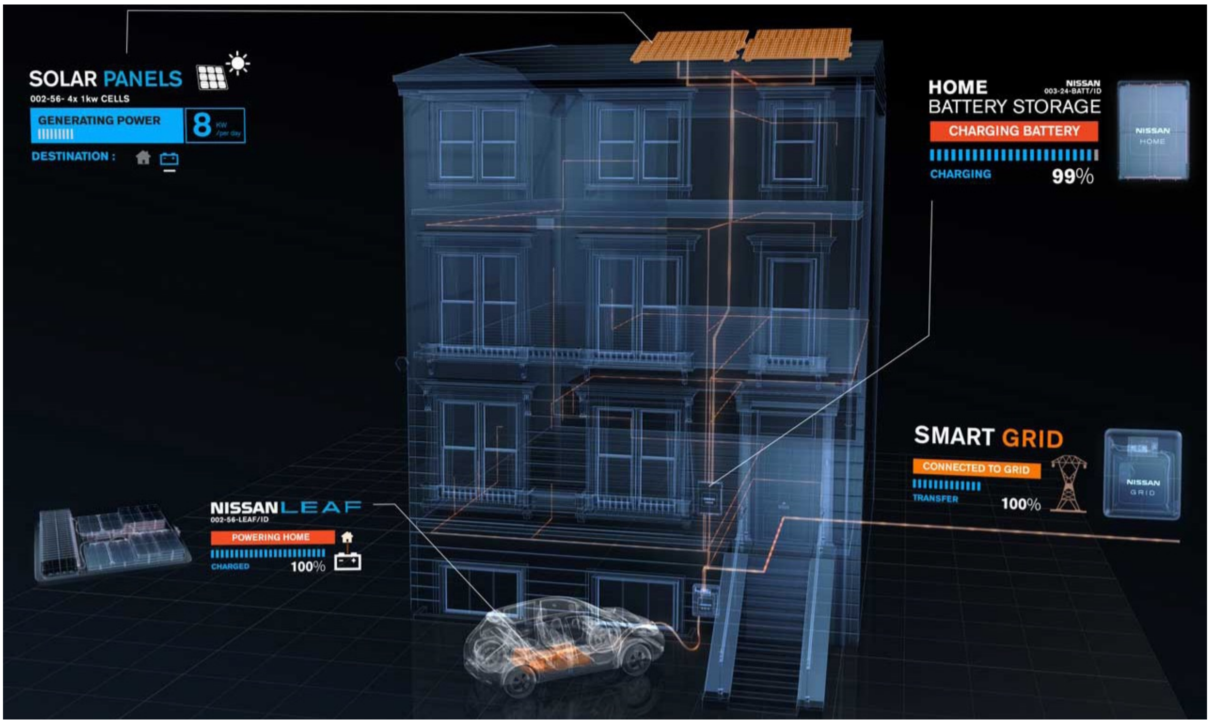

Figure 8 Energy system of a dwelling where solar energy in combination with the car battery could provide 24 hour use of solar energy (Foster + Partners)

Vehicle-to-grid
The batteries in electric cars can be used to store energy. Since any given vehicle is stationary most of the time, the grid can draw from the battery the electricity required to satisfy consumption peaks or compensate a drop in photovoltaic or wind power production. This approach, known as vehicle-to-grid (V2G), enables vehicles to bring flexibility to the electric grid that fuels them. Batteries can become a source of energy to supply households, offices etc. (Attias, 2017, P. 95). This means that car batteries have to be able to charge but also to discharge.

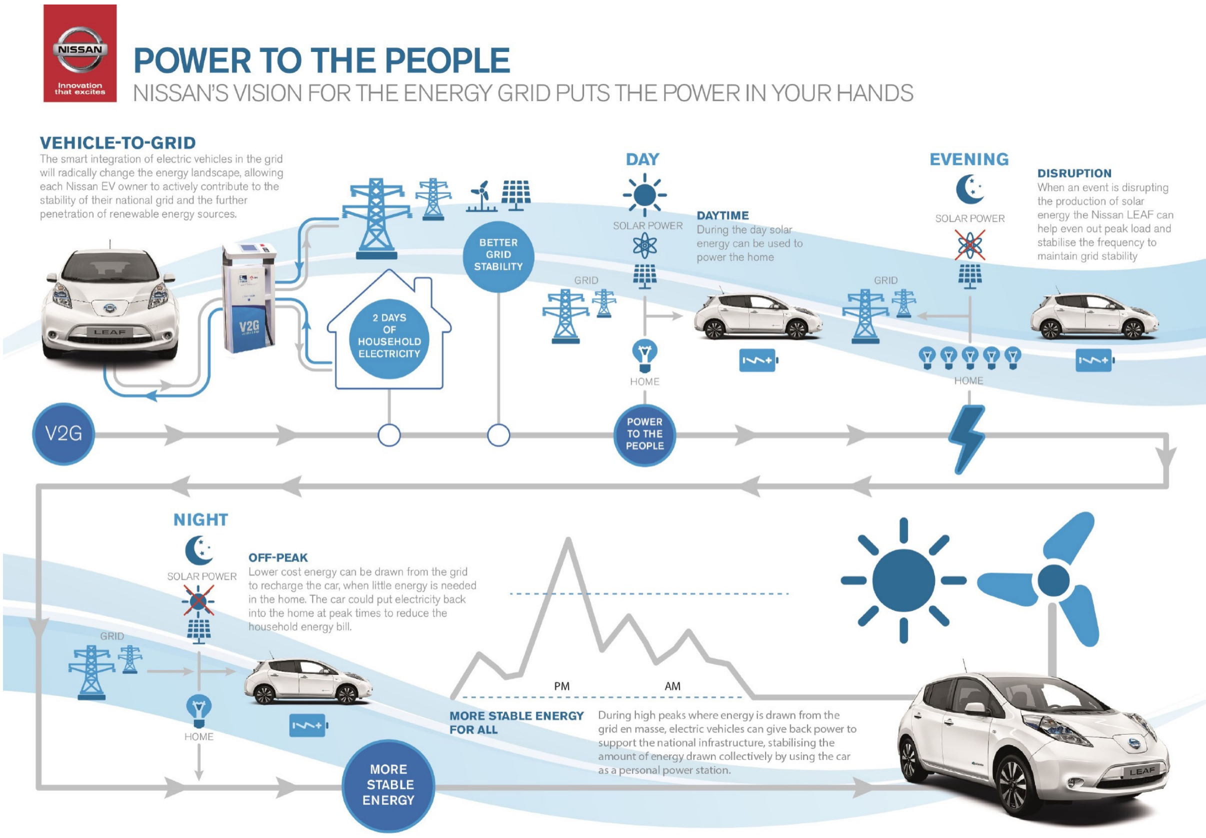

Figure 9 Nissan concept of the interaction between the car and the smart grid with the V2G system (Nissan, 2015)

Figure 9 shows Nissan, vision of the functioning of the V2G system. The smart grid, as described in the book 'Vehicle-to-grid: Linking electric vehicles to the smart grid', uses two-way flows of electricity and information to create a widely distributed automated resilient energy delivery network (Lu & Hossain, 2015, P. 1). The smart grid will meet environmental targets to accommodate an on demand response, and to support plug-in electric vehicles (PEVs) as well as distributed generation and storage capabilities. The electric vehicles will play a significant role in the electric power system. The connection of the vehicles can have a serious impact on the future smart grid. The power flow between the electric vehicles and the grid can be bidirectional if they have the function of V2G, which can be either as flexible loads (charging mode) or storage sources (discharging mode). To maximize the benefits of V2G, the future electric vehicle infrastructure must provide access to electricity from the smart grid, in order satisfy driver expectations and ensure safety (Lu & Hossain, 2015, P. 1). The storage of energy in the vehicle batteries could have a significant role in managing the peaks of energy demands in the smart grid. This is called peak-shaving, e.g. In the energy use of households there are two peak moments a day, one in the morning and one in the evening (see figure 10). In order to level the peak demands, we can charge the electric batteries at the peak of the PV energy generation and discharge at the residential peak demands. The timing of when to charge and when to discharge is a crucial factor in this functioning. The car is no longer part of the the problem, but now becomes part of the solution to the environmental issue and the energy transition (ElaadNL, n.d.).

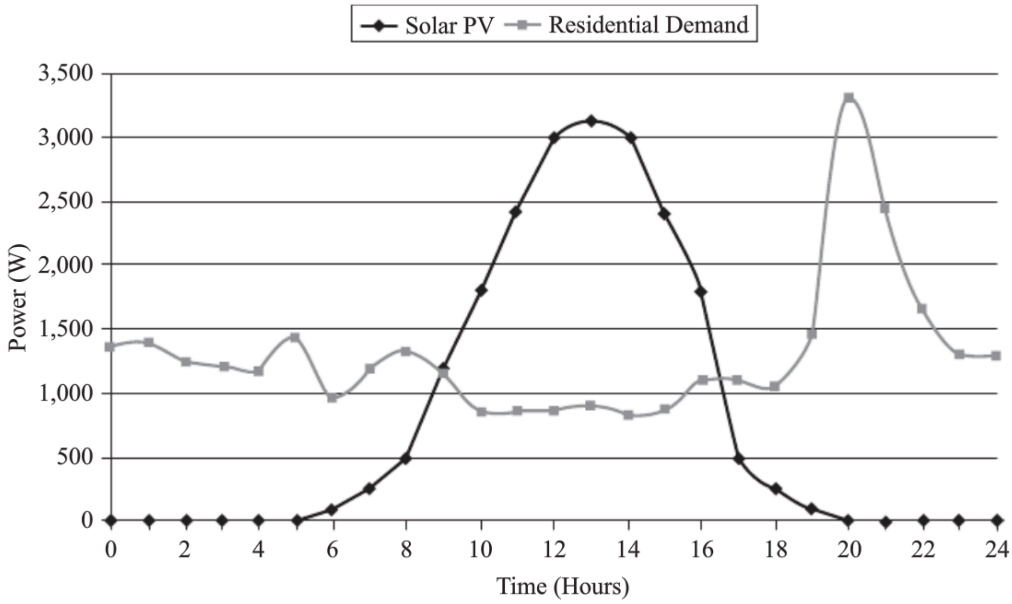

Figure 10 Solar energy sources can increase the availability of peak-period midday and charging and powering PEVs can be made more affordable (Lu & Hossain, 2015, P. 6)

V2G and the building

As visualized in figure 9 there are some parts that are needed to add to a building in order to make a V2G system work. The cars needs to be connected to a bidirectional charging unit. The current electric cars are connected to the charger by a cable, which the user plugs in when they park at a charging place. When cars will be self-driving, there will not be a use that plugs the cable in the charger, because the user already left the car before the car goes to park itself. This is why induction charging is getting introduced, which can be integrated in the floor of the parking spot (see figure 11). This charger will be connected to the grid of the building and also connected to the smart grid. The connection between the grids needs a transformer. In order to make use of energy in a sustainable manner the building where the cars are connecting to should produce as much of its own energy as possible, e.g. through solar or wind energy. Besides the use of the batteries in the cars also stationary batteries can be added to the buildings for back up, when the cars are not connected or don't have enough energy stored at a certain time. For example, Tesla Powerwall and Power Packs are suitable solutions for high performance stationary batteries that can be added to buildings (Tesla Motors, n.d.). The V2G system combined with a building is working with a lot of variables but can add to the overall performance of energy use in a building.

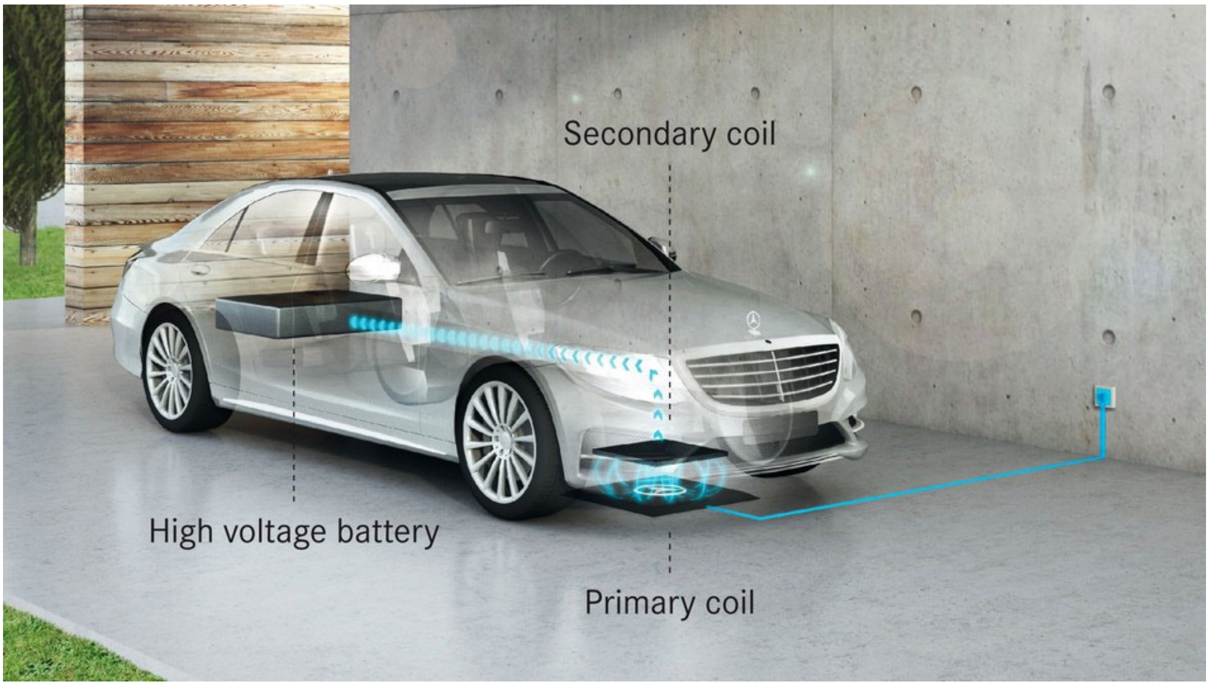

Figure 11 Inductive Charging of a car Battery (Mercedes-Benz, n.d.)

With the Battery Capacities of current electric cars, the V2G system is already promising. For example, The Battery of Tesla Model S, as mentioned before, has a capacity of 100 kWh, which can be used to drive over 600 km on a full battery (Tesla Motors, n.d.). An average household in The Netherlands currently consumes 3.000 kWh in one year, according to the Dutch National Institute for Budget Information (Nibud, 2017). This divided in 365 days of a year means that the energy that one average household needs a day is 8,2 kWh, so in theory an average household could be using one full battery for twelve days without needing the grid or electricity. Of course households in The Netherlands are still using gas which needs a lot of effort to replace with electricity. Also buildings are getting more and more energy efficient what can result in reducing the amount of energy consumption. This will demand very energy efficient solutions in future buildings, so we can be able to live and drive off of sustainable energy sources and not have a negative effect on the environment.

4. Conclusion

Assuming that cars are changing in the near future, how will architecture integrate and adapt to it?

Because the assumption is done that future cars will become electric and self-driving, after doing this research, in my opinion the main logical effects the future cars will have on architecture will be in the architectural design. In part 1 of the results, future solutions have been shown concerning parking and the arrival and departure. Also the contribution of the future cars by ways of V2G, as explained in part 2, will have a bonding effect regarding cars and buildings, because since the car is becoming part of the energy system has to be well integrated with the built environment.

By designing a way that the use of the future cars can provide in a higher comfortability, we can add quality to the life of the users. A self-parking system already would make arriving at a destination so much more comfortable, because you don't need to search for a parking spot, which can take up quite some time in busy areas like the city of Amsterdam. The danger in making the use of the car too comfortable is in attracting many people to use a car.

Sustainability of a building can improve by using a future car in the V2G system. Cars of today are polluting and have a negative image. By using the future electric cars that can support the energy efficiency of a building, cars will not be part of the problem any longer, but they will become part of the solution. I personally would be very enthusiastic if I will be able to have a beautiful car in the future, that is as clean as possible but still provides all the comfort. In combination with energy efficient buildings of the future we can reduce pollution of the environment as much as possible and live a comfortable life while being driven around in beautiful vehicles during our everyday life.

Discussion

First of all, the steps that have to be taken towards the future will take time, but I am convinced that electric self-driving cars will become reality. There are lots of challenges involved but communication between car manufacturers and architects will be the key in applying future solutions. It also requires a specific target group, car enthusiasts that are willing to take the first steps in to using this future car, so the main stream can follow.

The effects that are found in this research are for now logical effects, bound with what is seen in the development of the car industry. The future will bring more effects with it for sure.

There is more to be learned in the actual application of V2G and energy efficiency into the architectural design. Also more can be learned of analysing the use of the future cars. The technology in this field is rapidly developing, which makes this research topic an ongoing process.

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