Master thesis by Qiaoge Qu

# ELECTROLUMINESCENCE AUTOMOTIVE DESIGN APPLICATION

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*Integrated Product Design*
*Industrial Design Engineering*
*Delft University of Technology*

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# EXECUTIVE SUMMARY

This graduation project is cooperated with Delft University of Technology and Toyota Motor Europe together to explore the applications of electroluminescent materials in automotive design area. Electroluminescence (EL) is an easily manufactured and highly flexible lighting technology which can be designed in various patterns with DIY screen printing method. However, it is still little known and applied in product design. Toyota is interested in the technology and would like to discover how it can be embedded in cars either interiors and exteriors. Therefore, the project is conducted in a combined approach. It is a typical material driven design process. On the other hand, its design scope has been defined in automotive domain.

The report will start with understanding the EL material, including its working principle, technical features, current applications and benchmarking with alternative lighting technologies. It is necessary to discover the possibilities and limitations of EL material as well as its unique properties compared with other lighting methods. With respect to the automotive aspect, a trend overview in car industry is proposed, especially in its lighting system. Users are involved to help explore the driving context by means of interviews and observation, to gain knowledge of their experience and requirements of car driving. By synthesizing all insights from these analyses, the design direction is defined as vehicle to pedestrian communication in crosswalk scenarios.

With the design vision as a starting point, the ideation and embodiment design phases are planned, which aims to generate innovative ideas and improve the selected concept in a detailed level. A group creative session is conducted and various techniques are applied to facilitate the idea generation. After evaluating all solutions, the EL matrix direction is chosen to be improved to a complete concept. Additionally, a demonstrator will be built in the process to communicate the concpet to users. Therefore, it is important that the concept is technically feasible and can be made with current techniques.

# CONTENT

# ANALYSIS PHASE

This chapter starts with exploring the EL materials in terms of its properties, applications and comparison with other lighting technologies. It is followed by analysis on Toyota and automotive trends. Users are involved to help understand the current driving experience and context. With these insights integrated, a design vision will be proposed as the conclusion of the analysis phase.

# ELECTROLUMINESCENCE

The project starts with understanding the electroluminescent material regarding its technical and experiential characterization, in order to explore its unique qualities, limitations and user perceptions on it compared with alternative materials. This is an essential process for a material driven project. The knowledge of the material properties works as the foundation for the following design activities such as vision formulation, idea generation and prototyping making.

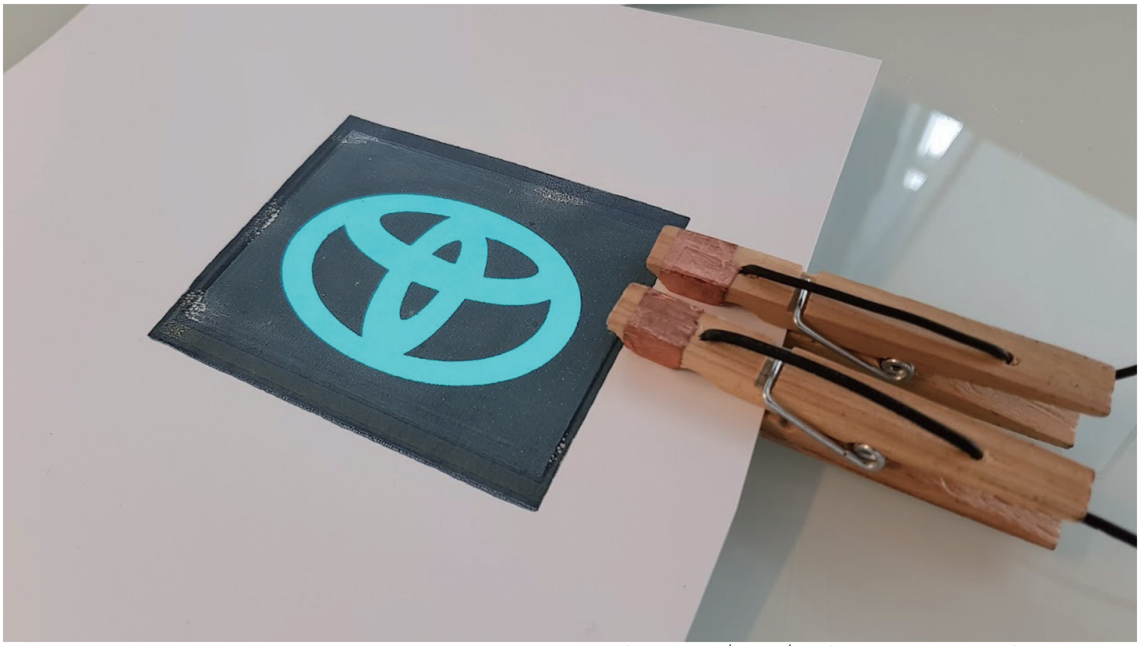


*Figure 1 - Electroluminescent screenprint on paper*

## WHAT IS EL?

In general, there are two ways of emitting light: incandescence and luminescence. In incandescence, light is generated as a result of heat. The most typical application of this phenomenon is incandescent bulbs, which can light up when an electric current passes through the filament and heats it to high temperatures because of its resistance. Luminescence, however, is a non-thermal way of producing light. In this case, lights are generated because of causes other than temperature(Miomandre and Audebert, 2016). According to its working principles, luminescence can be classified into different types, such as electroluminescence, photoluminescence, chemiluminescence, triboluminescence and cathodoluminescence etc.

Electroluminescence (EL), is a phenomenon of light emission from a certain material when it is exposed to a strong electric field. It is a non-thermal conversion from electrical energy to optical energy. EL consists of organic and inorganic categories using different active materials. Based on its working mechanism, inorganic electroluminescence can be classified further into injection EL and high-field EL. Injection EL is a phenomenon of light emission caused by the injection of minority carriers and recombination of electron-hole pairs in a p-n junction. Light emitting diodes(LEDs) are one of its most common applications. In the case of high-field EL, light is generated as a result of the excitation of luminescent centers by accelerated electrons under a strong electric field. Furthermore, the high-field EL can be divided into powder phosphor EL used mainly in lighting applications and thin-film EL represented by flat panel display(Vij, 2004). Based on different forms of electric field, the powder phosphor electroluminescence can be classified into alternating current powder EL(ACPEL) and direct current powder EL(DCPEL). This classification of different EL categories is illustrated in Figure 2 including their typical applications. The focus of this graduation project will be the powder phosphor electroluminescence, more specifically the ACPEL.

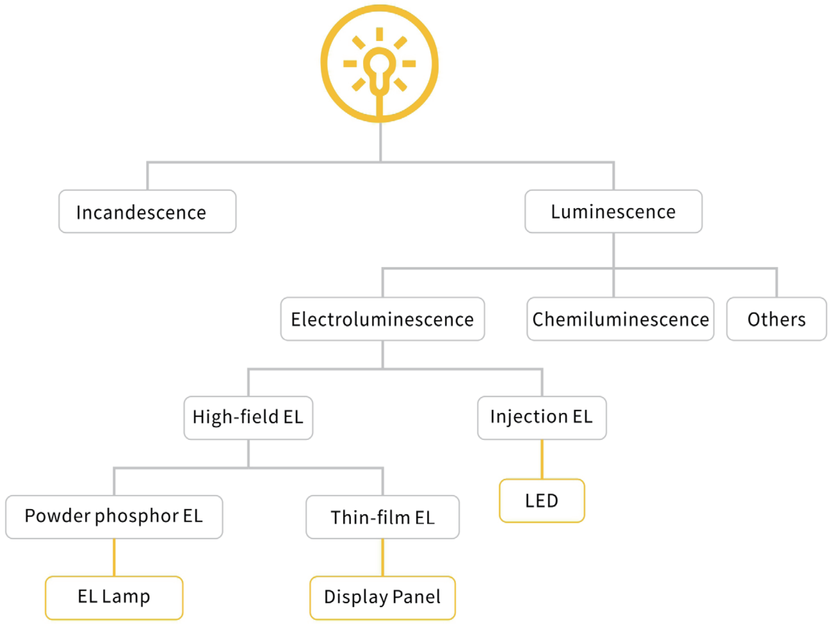



*Figure 2 - EL lighting types*

## EL structure

The typical structure of powder phosphor EL is shown in Figure 3. As mentioned before, in order to emit light, a high electric field has to show up for accelerating the electrons. This is achieved by the two layers of electrodes connected with an alternating current power supply. One layer of the electrode is required to be transparent to some extent, in order to see the light emission. This is applied commonly by the usage of a thin conductive film made of Indium tin oxide (ITO). The core and active part of the EL is the layer of powder phosphor material, sandwiched between two electrodes. One of the most widely used phosphors is the Zinc Sulfide type, incorporated with different metal substances, such as ZnS:Cu,Cl. The activator substance in the powder phosphor determines the color of the light emission.

In addition, a layer of material with high dielectric constant is placed between the two electrodes. It can help to concentrate the electric field across the phosphor layer, avoid the possibility of short circuit and reflect the generated light through the transparent electrode(Cayless, Coaton & Marsden, 2012).

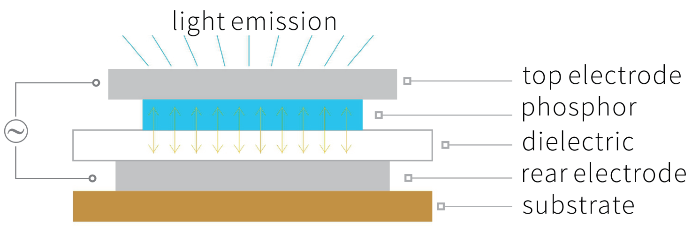



*Figure 3 - Typical EL structure*

# EL PROPERTIES

## Lamp form

### Types

Electroluminescent lighting is mainly available in three forms on market: EL wire, EL tapes/strips and EL panels. EL wire is thin and flexible, which can be cut into desired length without damaging its functionality. It has a copper core in the center, which is coated in phosphor and wrapped by copper wire. When an alternating current is powered between the core and wire, the phosphor coating is activated and generates light ("Electroluminescent Lighting Information | Engineering360", 2018). EL tape and panel have the similar glowing effect, but are more flat and wider, with larger lighting surface compared with the wire. EL panels are available with customized sizes and patterns based on user requirements.

Apart from these premade lamps, some companies have launched electroluminescent paints which allow users to freely fabricate their own EL lights, such as the lumiLor starter kit (fig.6). It includes the essential paints, electronics and accessories, with which beginners can be guided to be an applicator quickly by means of spray guns.

*Figure 4 - EL wire, tape and panel*

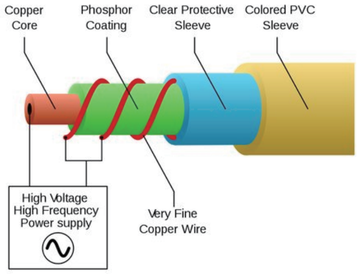



*Figure 5 - EL wire structure*

*Figure 6 - LumiLor starter kit*

### Thickness

Due to its sandwiching structure of ink layers, EL lamps are featured for their thinness. It can reach thickness lower than 0.3mm.

### Flexibility

With different substrate and electrode materials, EL devices can be manufactured in high flexibility. It means they can be easily bent to fit desired patterns or dimensional structures, allowing a multitude of applications. The bending radius can be low to 5mm.

## Powering

### Source

Figure 7 - 4XAAA pocket inverter

EL lamps operate in the voltage of 60 to 250V a.c. and at frequencies of 50 to 3,000Hz. This is commonly achieved by a power inverter to transform direct current to alternating current with specified voltage and frequency. No extra ballasts are required to help regulate the driving current. However, it is noticeable that the inverters are slightly audible in the usage. Additional features like sound activation, adjustable voltage and frequency etc. are available as well.

### Power consumption

Electroluminescence is an energy efficient way of converting electricity to optical energy. It requires low power consumption. This is partly due to its low heat generation and infrared, violet emission.

## Light output

### Brightness

The brightness of EL lamps depends on various factors, such as the phosphor particle size, dielectric constant, thickness, driving voltage and frequency. In theory, the brightness enhances with increased powering voltage and frequency, with the cost of compromising its lifetime. It can be concluded that EL lamps in general show low lumen output, with initial brightness up to 110cd/m2 or so, which is not highly visible in bright ambience.

### Colors

Figure 8 - Multicolor EL tape

The color range of EL lamps depends on the activators of phosphor materials. They are available in rich color options practically (fig.8), including red, yellow, green ,blue and white. The most efficient lamp emits blue-green color (Simpson,2003), as it is similar to the most sensitive color of human vision and therefore appears brightest.

### Homogeneous light

The light emission of EL is not directional. It emits evenly distributed and soft light from the phosphor area, causing no glare for observers.

## Cold light source

EL lamps are regarded as cold lighting source, as their lumen output is not generated by heat. In usage EL devices emit quite limited heat, which means their temperature will never rise dramatically, only a few degrees higher than the ambient temperature.

## Translucence

In off state, EL devices can be made in high translucence by embedding see-through dielectric, conductive and substrate layers.

## Lifetime

EL lamps do not suffer from sudden failures but gradual decay of cells over time, expressing decreased brightness. The lifetime of EL devices is defined as the time during which their brightness is decreased to half of its initial value. It is mainly influenced by the driving conditions including voltage, frequency, brightness, and environment conditions such as temperature and humidity (Vij, 2004). With the advances in EL materials, its lifetime has improved dramatically, reaching more than 3,000 hours in recommended usage situations.

## Eco-friendliness

EL devices are environmentally friendly and can be landfilled, as they do not contain hazardous materials which need special disposal.

## Operating environment

### Temperature

EL devices can operate in temperature range from -40 to over 100 degrees Celsius (Simpson,2003).

### Waterproof

EL lightings are waterproof as long as their active components are properly covered. Most EL products on market are fabricated with protective layers such as PVC to guarantee that. Even though it is weatherproof, long term usage in outdoors might accelerate the decay of EL cells due to excessive UV exposure.

### Impact resistance

As EL lamps do not require additional electronic components, they are impact resistant, suitable for environment with vibrations or movements.

## APPLICATIONS

This analysis starts with gathering current usages of EL material on market and classifying these examples according to their application fields to give a brief overview. It helps to further understand the material in practical aspects and provide insights on the relationship between its technical properties and usages, in terms of both limitations and strengths. The functions EL can perform will be discussed as well.

Even though EL material has not been massively commercialized, it is being used in various domains, showing a promising application prospect. According to the grouping, there are mainly seven domains, namely: advertising, architecture lighting, vehicles, electronics, fashion & accessories, safety equipment, art & design.

## ADVERTISING


Bombay Sapphire gin package | Liquor | Paper printing EL | Foxy bingo poster
EL billboard | Amazon EL billboard in New York

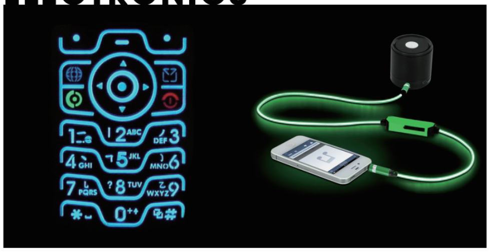
## ARCHITECTURE LIGHTING

Kensington Palace's light sculpture Luminous Lace | EL tape interior
EL bar decoration | outdoor stairs

## VEHICLES


EL car painting | First EL paints to light up Airbus jets
EL wire car interior | EL Road Event | Hyundai car wrap

## ELECTRONICS



Phone keyboard lighting | EL cable

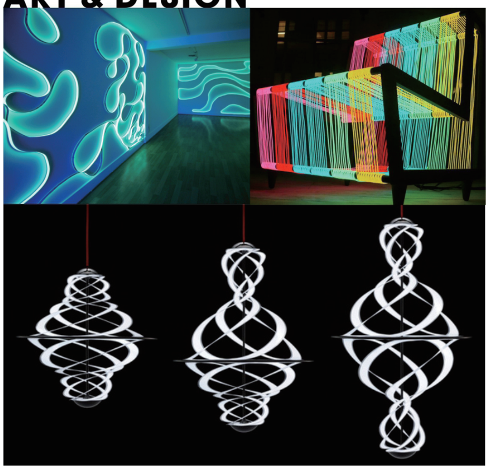
## FASHION & ACCESSORIES


Vega Zaishi Wang dress | EL Dancer suits
T-shirt with EL wire | EL flower | Live concert

## SAFETY EQUIPMENT

Light tape jacket | Motorcycle helmet

## ART & DESIGN



Homage to Burle Marx | Disco chair
Lactea lamp

## Night visibility

Electroluminescence, in essence, is a way of generating light. Therefore, its basic function is to increase visibility. As explained in EL properties session, it shows great advantage in terms of soft light without glare, however is low regarding its lumen output. These properties determine that EL is mainly applied as backlight to illuminate vehicle meters, phone keyboards, watches, safety vest and more in dark ambience. It would not be feasible to adopt EL devices for general lighting propose. In addition, it has been noticed that EL is commonly applied as an area lighting source instead of linear or point


## Attention drawing

Light is a classic and powerful way to draw attention when used appropriately. For example, accent lighting in shop windows is everywhere on street to highlight its new release and attract passengers. Since human eyes are quite sensitive to changes in light output and colors, dynamic lighting can not only draw attention more effectively, but also lead customers focus through the illuminated area (Main.invisua.com, 2018). Therefore, in its practical applications of advertising, companies are attempting to convey their brand image with graphics or animated motions by means of EL material, which allows to be embedded on diverse materials such as


## Personal identity

Electroluminescent high flexibility allows the possibility for customization and DIY in a convenient and cheap way, such as by painting or EL wires. According to Ligas(2000), people can differentiate themselves from others not only by behaviours, but also through symbolic products beyond their function meanings. DIY fulfills the needs of uniqueness and personal identity since users can possess individual products instead of those mass manufactured ones. As a cold light, EL usually conveys the impression of modern look. It is popular in the fashion field and wearable applications to present a cool lifestyle.

### Atmosphere creation

Light has been used widely as a medium to express information and create certain atmosphere by architects, designers and artists. It has been proved that human impression of an environment can be shaped or influenced by lightings, such as spaciousness, relaxation or tension, private or public space, pleasantness, perceptual clarity and spatial complexity (Flynn, Spencer, Martyniuk & Hendrick, 1973). These atmospheres can be manipulated by adjusting light intensity, colors, direction, movement and more. For example, peripheral and non-uniform lighting can help to express relaxing and pleasant impression. EL lights present high level of freedom in terms of their distribution and easy installation, therefore are being widely applied in interior design.

However, it should be stated that the actual outcome depends a lot on the circumstances, user personality and culture background. As a medium for designers and artists, EL shows great advantage in the flexibility of pattern creation and structure composition with its unique lighting effects.

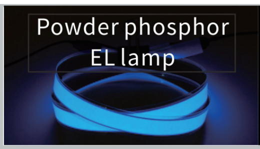
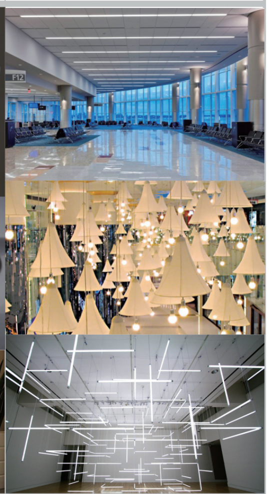
### Emotion expression

EL lamps can be adopted to help express emotions purposely or unconsciously. Considering it as an independent factor, when people are exposed to different lighting effects, various emotions can be evoked already based on our cognitive appraisal.

## BENCHMARKING OF LIGHTING TECHNOLOGIES

The benchmarking analysis presents an overall comparison of various lighting technologies in terms of their technical properties and applications. In this way, The powder phosphor EL lamp can be positioned among alternative lighting methods, providing insights about potential usage areas and identifying its limitations, strengths as well as unique characteristics (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015). It can be valuable in the exploration of substituting EL lamps for current lightings or formulating design vision for further ideation.

As illustrated in the following table, nine luminous methods have been selected for the benchmarking, based on their similar working principles, lighting effects, customizability or emerging technologies. In the property part, emphasis has been placed on their lamp form, lighting quality, possibility for customization, together with power efficiency. Regarding to applications, some of their typical or inspirational examples are listed, with a short summary of the current usage areas. Note that the numbers in the chart such as lighting efficiency and lifetime may vary with different lamps and environmental conditions. The data are mainly used for indication and qualitative analysis.

| | LIGHTING TECHNOLOGY | Powder phosphor EL lamp  | LED  | OLED  | Fluorescent lamp  |
|---|---|---|---|---|---|
| TECHNICAL PROPERTIES | Working principle | phosphor material under electric field | P-N junction diode emits light when activated | a film of organic compound emits light | UV light by mercury vapor to excite phosphor coating |
| | Lamp type | EL panel, tape, wire and paint | LED bulb, tube and strips | OLED panel, both flexible and rigid | fluorescent tube and compact lamp |
| | Lamp dimension | very thin | various shapes | very thin | relatively large |
| | Lumen output | low, 50 cd/ $m^2$ | high | medium | high, flicker at a rate |
| | Light distribution | diffused, soft without glare | point source, directional light | diffused light with no glare | even light source |
| | Lighting color | rich options, blue, red, green and white | full color mixing, with RGB and white | color tunable, mainly natural white | cool, neutral and warm white |
| | Flexibility | very high, can be bended | high for LED strips | high for flexible panel | N/A |
| | Customization | very high, possible for desired patterns and structures | high, easy to control its colors and lamp distribution | high, can be shaped in different structures | N/A |
| | Efficiency | high | very high, 80 lm/W | very high, 90 lm/W | medium, 57 lm/W |
| | Power source | AC, around 100V with an inverter | DC, with an embedded driver | DC, low voltage | AC |
| | Heat emission | low | low | very low | medium |
| | General Lifetime | 2000 hours | 25,000 hours | 2000-4000 hours | 8000 hours |
| | Purchase price | high | medium / high | high | low |
| APPLICATIONS | Examples |  |   |  |  |
| | Applicated area | advertising; back lights; art & fashion; customization; decorative lighting | indoor and outdoor lighting; automotive; advertising; decoration | indoor lighting; automotive; decoration | indoor lighting, such as office, shop and classroom |

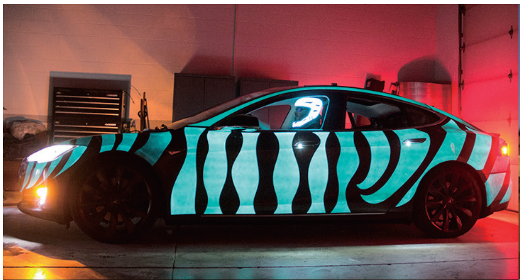
| Halogen lamp | Neon lamp | Chemiluminescent lamp | Luminous paint | Optical fiber |
|---|---|---|---|---|
| incandescent lamp filled with halogen gas | gas in the tube is ionized under a high voltage | emission of light resulting from chemical reaction | phosphor materials exposed to long-wave UV frequencies | light is transmitted via total internal reflection |
| halogen bulb | tube | glow stick | fluorescent and phosphorescent paint | end emitting, side emitting, optic fabric |
| various shapes, small | various shapes | small | N/A | very thin |
| high | medium | low in general | low | low |
| all directions | diffused light | diffused light | soft light | sparkle |
| warm white | rich colors with different gases | rich color options | various, typically blue and green | depending on the lighting source |
| N/A | N/A | medium | N/A | high |
| N/A | medium ,shape of the neon tube can be designed | medium | very high, can be painted freely | high |
| low, 17 lm/W | medium, 50-65 lm/W | N/A | N/A | N/A, high transmission |
| low to high voltage | AC/DC | N/A, no electricity | N/A | N/A |
| high | medium | low | medium | N/A |
| 1000-4000 hours | very long, 8 years | very low, one time use | N/A | N/A |
| low | medium | low | low | high for optic fabric |


| | | | | |
|---|---|---|---|---|
| accent lighting; stage lighting; automobiles | indicator lights; signs; decorative lamps; art and architecture | recreation; campers; military use | decoration; art and body paint; safety | wearables; decorative lighting; architecture |

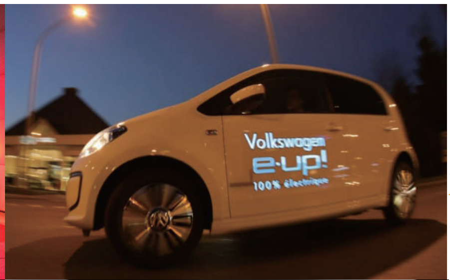
Compared with the listed luminous technologies, EL lamp is weak in terms of its low lumen output. This property can be considered as a limitation, which means task lighting or illumination in high brightness ambience will not be applicable. However, it shows advantage in its homogeneous lighting without glare, ideal for backlighting or decorative propose.

With regard to form and flexibility, most of the lamps are already pre-made in their shapes with low possibility for customization. EL, however, is extremely thin and allows for bending or cutting. It can be used to create personalized EL lights with complicated patterns or geometric structures via low-cost screen printing, which otherwise is not feasible with conventional lighting methods. Due to the ink sandwiching structure, EL can be embedded on different substrates such as metal, glass, paper etc., to freely light up desired areas.

One limitation of EL lighting lies in its low controllability of pattern and color changes. Once its structure is settled, it would be inconvenient to shift the color or pattern displays as freely as LED for example, since they mainly depends on the phosphor materials and distribution area which cannot be manipulated easily.



*EL painting*




*EL car sticker*

*LED strips*

*OLED BMW M4*

*Optical fiber*

Among the listed lamps, EL shows great similarities with LED strips, OLED flexible panel and optical fiber. All of them are flexible, allowing to be manipulated to desired shapes and patterns to some extent, therefore suitable for decorative lighting.

The uniqueness of EL lamp shows in its seamless integration on the substrate with delicate patterns, which can create the self-luminous illusion of embedded materials instead of the impression of an external lighting source. This is especially true when the EL is applied in large areas. The other special property is the possible dynamic interactions with it. Because of its sandwiching structure, it is possible to experiment with various compositions and activate the light with novel methods such as pressure (fig.9), water (fig.10) etc. to establish playful experiences. These two features make EL a cool artificial lighting medium, challenging the cognition of the public about how a lamp should be and the interactions they can perform.

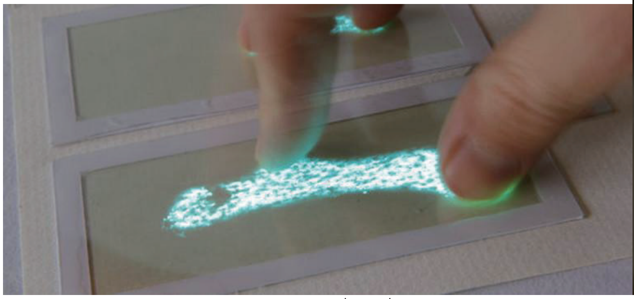


*Figure 9 - EL pressure activation by Claus*

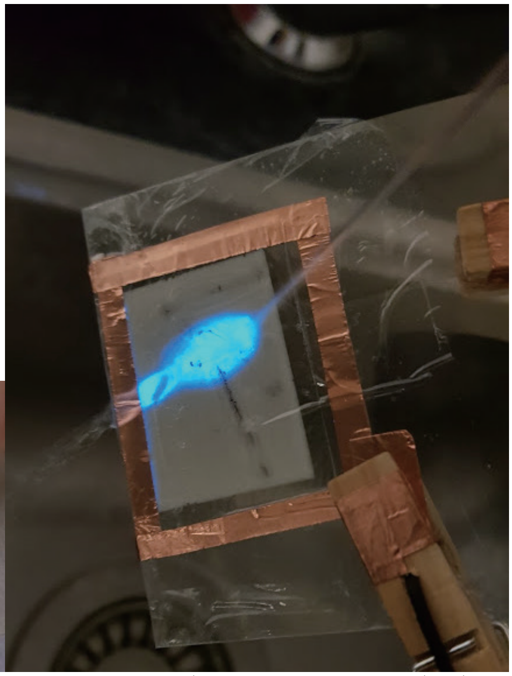


*Figure 10 - EL water activation*

## Experiential quality

According to the analysis from former EL project conducted by Claus (2016), the positive feedback attached to EL lamps is mostly evoked by two aspects: dynamic experience with the samples and their aesthetic enjoyment. The dynamic quality comes from their possibility for interaction and high level of flexibility, which usually expresses with imaginative, unusual and playful feelings. The visual appealing is due to the delicate pattern design and translucent characteristic, with the impression of decorative and ambient lighting.

# TOYOTA

As a key stakeholder of the project, it is meaningful to explore the Toyota brand in terms of its public image, mission & vision, and innovations. These insights can help to shape the developed concept fitting more into Toyota brand, to differentiate it from other competitive automotive manufacturers for example.

As a global leader of the automotive industry, Toyota positions itself as a pioneer in the future mobility, highlighting their pursuit for a secure and eco-friendly driving experience. This vision is in accordance with its current brand image and developing strategies. According to the car brand perception survey(2014), which has investigated customer opinions towards different automobile brands in terms of their quality, safety, performance, value, fuel economy, design and innovation, Toyota has showed compelling advantage in fuel economy, due to its massive launch of hybrid vehicles with superior energy efficiency. For safety concerns, Toyota does stand out, nevertheless, its competitor Volvo turns out to be a clear option for customers.

In general, Toyota expresses a strong brand identity as a green driving option and choice for family use. Their automobiles stand out among other competitors with reliability and high fuel-efficiency. The weakness lies in their unstylish appearance design, which is perceived unattractive for young generations.

**GREEN**

*"I recognize it as an energy-efficient brand. They've launched the Prius hybrid driving everywhere in the U.S. "*

**RELIABLE**

*"It's a reliable brand with a lot of tests. Toyota cars never fail in the driving."*

*"It's not as expensive as German cars, an affordable option with fine quality."*

**FAMILY USE**

*"They are not for young generations, mainly for family use."*

## Innovation

Technology innovation is a solid basis for Toyota to develop new vehicles. Their vision is to make better eco-cars by means of improving conventional technologies and exploring new domains. Guided by its vision, Toyota's mission is to constantly innovate and continue developing new vehicles with high quality and environmental friendliness.

Currently, it focuses mainly on environmental technology, safety technology, automated driving and intelligent transport systems etc.

There are two approaches Toyota has adopted to enhance eco-friendliness of automobiles, namely energy-saving adaptation in gasoline vehicles and fuel diversification. Apart from conventional petrol, it has been working on making use of other forms of energy source, such as electricity, gas fuels, biofuel and hydrogen. This is best illustrated in its new launch of fuel cell vehicle Mirai, which uses hydrogen as powering source with only water emission. This is considered as the ultimate form of eco-cars and will make great difference to our environment when launched massively.

Safety is the top priority of Toyota with the goal to eliminate traffic accidents and offer a secure driving experience. It integrates cameras and radars to better sense driving conditions such as road signs and other vehicles, to make sure the vehicle can react instantly under dangerous situations. Typical features include brake assist, Toyota safety sense and traction control.

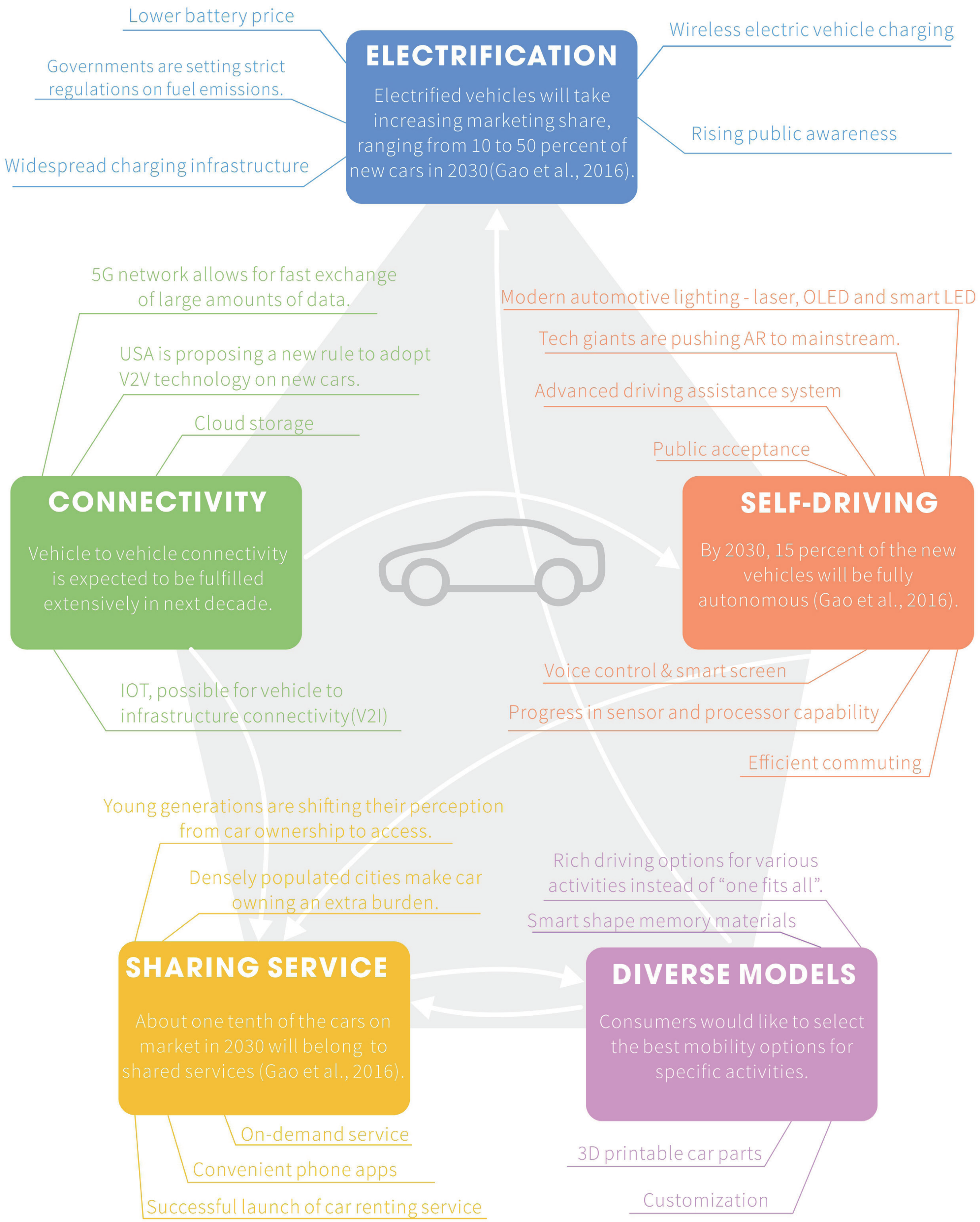
Automated driving is under development as well. By means of this technology, Toyota is aiming for providing safe, efficient and highly free mobility experience for everyone. Its basic principle is an seamless integration of driving intelligence, connceted intelligence and interactive intelligence. Intogether, these technologies can shape a new relationship between cars and drivers.

*Figure 11 - Toyota fuel cell car Mirai*

# TRENDS ANALYSIS

The trend analysis is conducted to indentify the tendency in automotive domian for the following decades, which can help to gain insights on the future context. Considering that EL material is a lighting method, the analysis also focuses on car lighting systems, both interior and exterior.

# AUTOMOTIVE TRENDS



## AUTOMOTIVE LIGHTING TRENDS

With the advances in lighting technologies, car manufacturers are driven to keep updated and integrate these innovations into their lighting design for better performance, security and distinctive design.

### Exterior lighting

Current automotive headlamps on the market are mainly halogen, xenon and recent LED lighting sources. In the short term, LED is expected to be adopted in more automotive lighting applications with its decreased cost and high performance. Also, there will be more lighting content in vehicles. In the longer term, new lighting technologies will be widespread utilized in automotive lighting system (Mukish, Boulay and Virey, 2016). Typical examples include laser and OLED lighting. Laser lighting commercial car is firstly launched in BMW i8 (fig. 12), with the extraordinary brightness and long range with small dimensions. It can present a better night vision compared with conventional lightings. The OLED lights (fig.13) are often embedded in rear lighting, with high level of flexibility and homogeneity. It opens up the possibility for car lighting design. In addition, smart functions like advanced front lighting systems (AFS) are in progress, which can adapt its beam automatically based on the weather, road condition, driving speed and road users etc.

*Figure 12 - BMW i8 laser lighting*


*Figure 13 - OLED tail light*

### Interior lighting

Adoption of ambient lighting has been an emerging trend in automotive interior design. It refers to the indirect lighting which provides an area with comfortable level of illumination, causing no glare or disturbance. It can contribute to deliver the perceptions of orientation and space spaciousness to drivers, as well as enhance the feelings of comfort, security and vehicle appreciation (Mathas, 2018). In addition, it is effective to decrease the level of night driving fatigue. In terms of marketing, it opens up the possibility for the brand differentiation from competitive vehicles, by standing out the brand identity and creating consistent interior styles ("Innovative interior lighting", 2018).

The colors of ambient lighting plays a key role in affecting the driving experience. According to Mathas (2018) and consumer ambient lighting preference research (Tuzmen, 2013), blue is the most preferred option, as it is perceived brighter and provides better visibility and sense of orientation. Orange is regarded as more luxury and better quality, but with higher possibility of distraction. The most desired illuminated area is chosen to be the central console or shifter area compared with other parts such as instrument panel, cup holders and interior door handles.

*Figure 14 - Automotive ambient lighting market, 2017*

# DRIVING EXPERIENCE

## USER INTERVIEW

The interview is arranged in the early phase to explore driving activities and zoom in on the automotive lighting conditions. It aims to gather general and explorative feedback from respondents regarding their opinions based on individual car using experience. Therefore, it is conducted in a semi-structured way, which has a list of pre-determined open questions with the possibility for further and flexible responses.

Five participants have been interviewed based on the questionnaire listed below, which mainly covers three aspects, including general driving process, car lighting and desired qualities. The transcription of their detailed replies can be found in Appendix A.

### Questionnaire

*1. Have you driven a car before?*

*2. In which situation will you choose to drive a car e.g.weather conditions, travel distance or group trip?*

*3. What activities do you like to perform in the driving process?*

*4. What do you enjoy most in your driving experience? How do you feel?*

*4. What are the frustrating situations?*

*6. What's the difference between driving in daytime and at night?*

*7. Are there inconveniences you've encountered in night driving, any examples?*

*8. How would you evaluate your car's lighting considering the interior and exterior respectively? What problems do they have?*

*9. What kind of lighting (features) do you want? Any requirements for night driving?*

*10. How would you envision your ideal car in the next 5-10 years, or your most desirable driving features and experiences?*

# CAR DRIVING INTERVIEW INSIGHTS

## CAR USING SITUATIONS

Bad weather conditions

Inconvenient public transportation

Family visit

Trip and picnic

A fast option, emergent option

No driving in big cities due to difficult parking *

## ACTIVITIES IN THE DRIVING PROCESS

Listen to music and radios

Listen to audio books

Phone checking

Texting

Talk with other passengers

## MOST ENJOYABLE ASPECTS / FEELINGS

Freedom - flexible time and rich destination options

Be in own space - being alone, enjoying music and heater, not disturbing others

Feel in control of the car and its parts

Be independent

## FRUSTRATING SITUATIONS

Traffic jam in rush hours

Need to stay focused all the time

Inefficient - cannot work on something else, especially in long trips

Distraction - passengers are talking too loud

## NIGHT DRIVING COMPARED TO DAYTIME

Less traffic on the road - fewer pedestrians and vehicles

More cautious and focused - dark ambience

Calm and less distracted

More tiring

A boring experience - nothing to arouse interest

## NIGHT DRIVING INCONVENIENCES

Wrong light settings form other vehicles

Light reflection in the mirror from cars behind you

Extinguished street lamps in highway

Brighter lamps in raining days

Distracted by the dome and panel lights, especially for those with digital dashboards

Bright but not enough with its limited distribution

## DESIRED LIGHTING QUALITIES

Ambient lighting - stay on but not disturb drivers

Smart lighting which can adjust its output according to the context

Separated lamps for drivers and passengers

Integrated lights into the material

Evenly distributed lights

## ENVISIONED CAR FEATURES

Luxury interior

Smart assistance - understand and predict needs

Automatic features

Contradictory attitude towards self-driving cars

## NIGHT DRIVING OBSERVATION

As discussed in the EL properties, EL lighting is not highly visible in bright environment such as daytime, therefore, it is reasonable to emphasize more on the night driving context. The observation session is set up to look into the night driving experience in the real scenario, mainly focusing on the behaviours and emotions of the driver and his interaction with the environment in the process. The functions and using context of lights at night are explored as well from the driver's perspective. This research is particularly valuable for me who has limited understanding of car steering before. It presents a more direct and vivid driving image, especially with the confrontation of unexpected situations.

### Method

One experienced driver has been invited to offer a short-distance ride when it is dark outside. In the process, me as an observer, will take pictures of the ongoing interactions and ask the participant to explain his action and feelings in the meantime. He is informed of the project background in advance and encouraged to talk freely about his thoughts. The research ends with a short interview for extended detailed information. The questions are listed below.

*1. What do you need to pay attention to when driving in terms of vehicle-related aspects and the whole environment?*

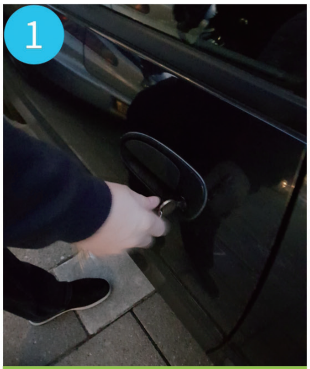
*2. What activities do you usually do when driving?*

*3. In night driving, what can be the inconvenient situations?*

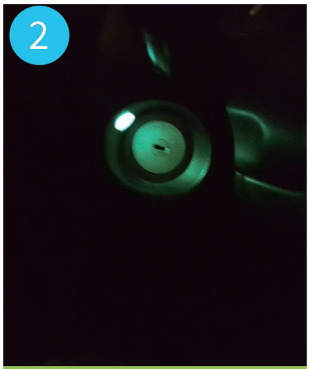
*4. What do you feel in general about driving?*

*5. What are your most desired driving experiences/features/concerns?*

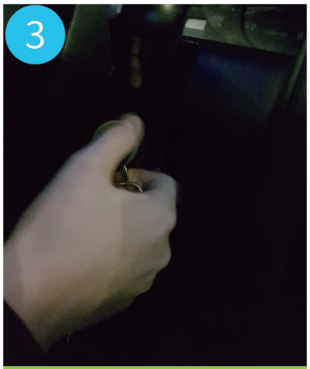
# STORYBOARD OF DRIVING



Open the door with key



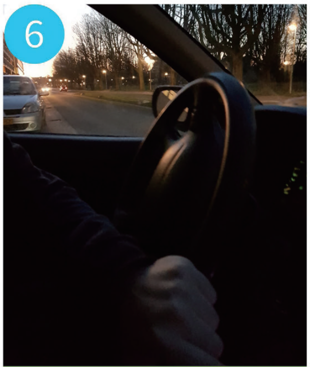
Key hole lights up



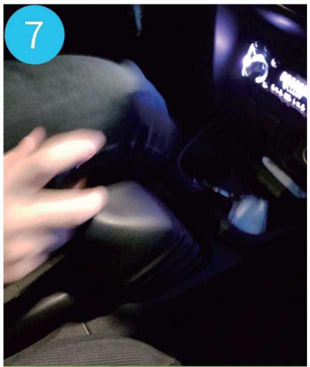
Start the engine

Roll down the window

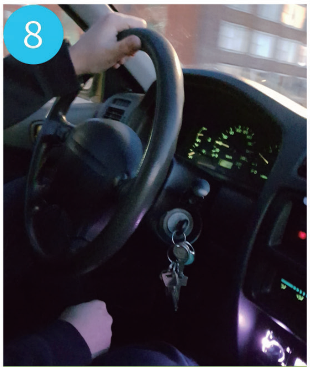
Panel lights up
Turn on the radio



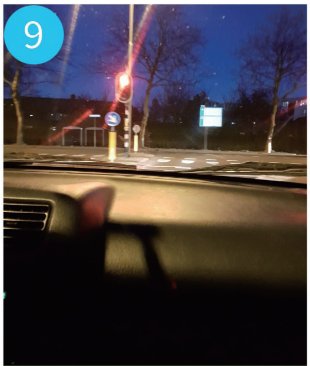
The car moves



Adjust the gear stick



Turn left



Stop at red traffic light

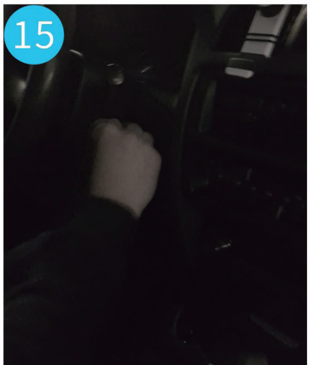
Meet a cyclist without bike light

Stop behind other cars

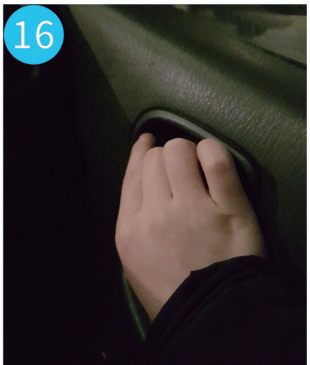
Wait for cyclists and other cars at crossroads

Turn on the overhead lamp looking for a pen

Pull handbrake



Stop the car and remove keys



Open the door and get off

## Insights

There's not so many vehicles on the road at night, so we haven't gone through traffic congestions in the process. The whole trip proceeds smoothly in general, with only several stops at traffic lights and crossroads. The participant has been driving for more than twelve years, expressing a relaxing and enjoyable attitude towards the activity. However, some unexpected situations like improper operation from other drivers do shift his feelings to more cautious and annoyed aspects.

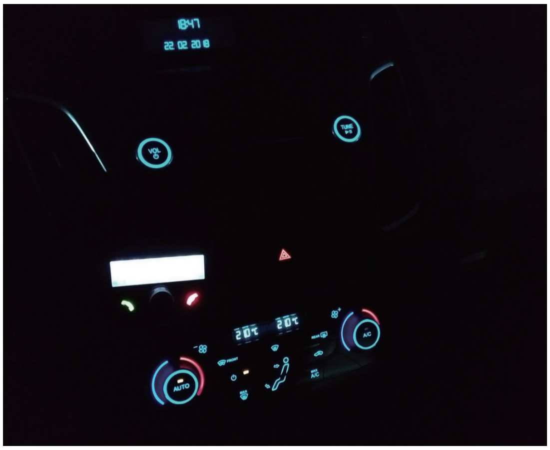
### Seeing and being seen

In the dark ambience, lighting has become a irreplaceable medium, not only to illuminate the surroundings for better visual effect, but also as a symbol to indicate the existence of your vehicle to other drivers or pedestrians. Based on our living experience, the public has formed certain impressions of how lightings from different transportations should look like. However, this can be unreliable sometimes. There are cars on the street with one headlamp broken. The participant mentioned it can be misrecognized as a motorcycle from a distance because their lights are similar in this situation. In addition, you can barely notice the cyclists without bike lights on especially when driving at high speed. It is realized that the association between vehicles and their lightings are weak and ambiguous, regarding the function to improve visibility at night.

### Communication

There are intensive rules and regulations to guarantee the understandability of the communication among vehicles by means of lightings, such as the embedded turn signals. However, it is not standardized yet for the conversations between vehicles and pedestrians. In those cross roads without traffic lights, drivers need to indicate to passengers and cyclists whether they are identified and can get through or not. In daytime, this is normally fulfilled by means of hand gestures, while at night lighting seems to be the option for communication by flashing the headlamp etc. This can be ambiguous due to the invisibility of driver indications and unclear meaning of the behaviour. As indicated by the image twelve of the storyboard, the cyclist on the crossroad was waiting and hesitating whether he can cross or not, even though the car has completely stopped.

### Interior lighting



The interior lighting of automotives can be classified into several types according to their locations and functions, such as console and button lighting, decorative lighting and overhead lights (dome lights). For dashboards and buttons, it is important to keep them lighting up in order to indicate their positions and increase the readability efficiently. It helps to shorten the time when drivers' eyes are off the road for safety concerns as well. When it comes to the dome light, drivers usually do not turn it on intentionally, unless he needs to look for some objects or other passengers would like to read. It is interesting to mention that in the process, my pen has dropped on the floor accidently, however the dome light cannot reach effectively to light up this area. In General, all these lights shall be soft and do not disturb drivers in darkness.

**Attention and experience**

Drivers need to be focused all the way and pay attention to various aspects in the process. For vehicle related data, their emphasis are mainly placed on the dashboard area, including the speed, driving distance and fuel storage. As for the environment, they usually notice weather and road conditions, traffic signs, vehicles and pedestrians around. One of the main concerns in the driving process is comfort, since more and more hours are being spent sitting in cars. This is reflected not only in the driving performance, but also in the added features such as seat, interior ambient lighting and air conditioning. In particular, the participant has emphasized his need for a smooth experience. He would prefer to slow down the car gradually instead of sudden brakes and start-up. Other considerations like safety and energizing aspects are mentioned as well.

## WORKSHOP

The workshop takes place with three car enthusiasts from different backgrounds. They are invited to share knowledge about cars and explore the driving experience as a team. It consists of three phases in general, starting from context exploration, activities & emotions to an early idea generation. The whole session takes place in an explorative way, encouraging free communication among all team members with postponed judgement.

### Context exploration

The workshop starts with context drawing to visualize the interactions in the driving process, with regard to vehicle itself and the whole environment respectively. Participants are invited to identify the touching car components in their driving experience with sketches or words and share the information with other members. In a larger context, the car is perceived as a whole and the emphasis has been placed on exploring driving scenarios, such as weather, traffic conditions, other vehicles and pedestrians etc. The gathered insights from these drawings have been visualized as shown on the next page.


DRIVING CONTEXT
WEATHER
PEDESTRIANS & OTHER VEHICLE
CAR TOUCHPOINTS
STEER
steering wheel
navigation/ console
gear shifter
dashboard
buttons
COMFORT
seat & seat control
air vent
arm rest
window control
NECESSITY
door handle
fuel cap
lightings
phone charging
safety belt
AMUSEMENT
music player
roof window
video screen
STORAGE
glove compartment
trunk
cup holder
STREET LIGHT
TRAFFIC SIGNS
50
CAR ACCIDENT
GAS STATION

## Activities & Emotions

After exploring the driving context, the focus of the workshop has been specified to driving activities and emotions. Activities refer to the purpose or possible scenarios of using a car, and emotions are related to the feelings in the driving process. Both topics are discussed by brain-writing with post-its and clustering gathered data in groups.

The generated activities have been classified into nine categories, namely routine task, goods transportation, social, race, vehicle related, environment, time pressure, new experience and trip, which is illustrated in Figure 15.

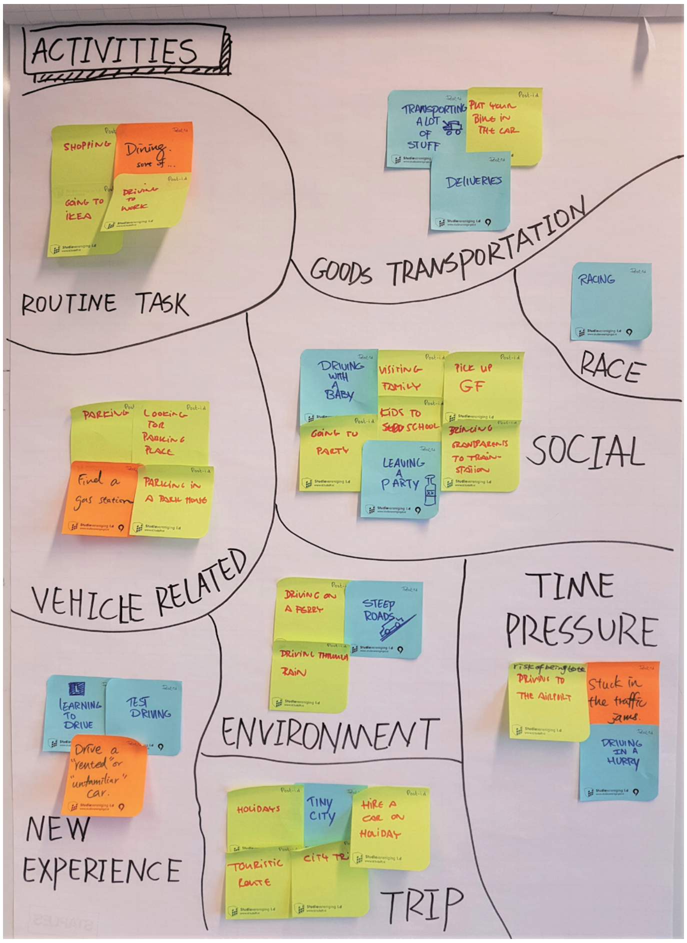


*Figure 15 - Clustered activities*

The emotions and feelings evoked in the driving process are various and context dependent. They are highly influenced by factors such as user personality, driving experience, weather condition, time, associated activities etc. They can be roughly classified into four categories - involvement, controllability, relaxation and other emotions, in both positive and negative sides. This grouping is visualized in Figure 16. On the other hand, they show great differences in terms of emotional intensity. Some of them are mild and lasting while others can be strong and temporary. The pyramid in Figure 17 shows this feature, which positions these emotions based on their level of intensity. However, it has to be mentioned that the emotion itself is abstract and comprehensive, leading to a subjective result which might differ due to individual perceptions.

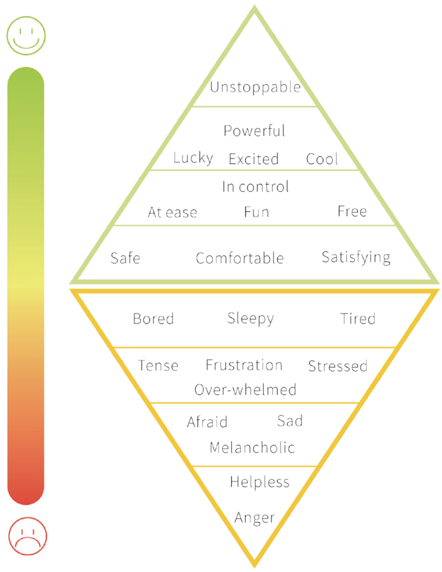



*Figure 17 - Emotional intensity*

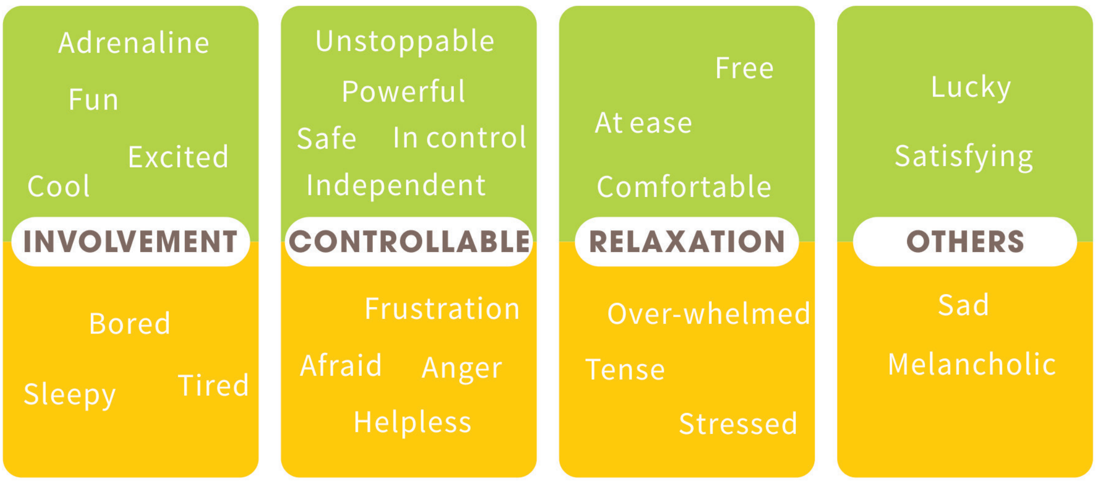



*Figure 16 - Emotion category*

## Early ideation

In this session, we have conducted a quick and divergent ideation, to explore how EL devices can be applied on automotives. Overview can be seen in the following image.

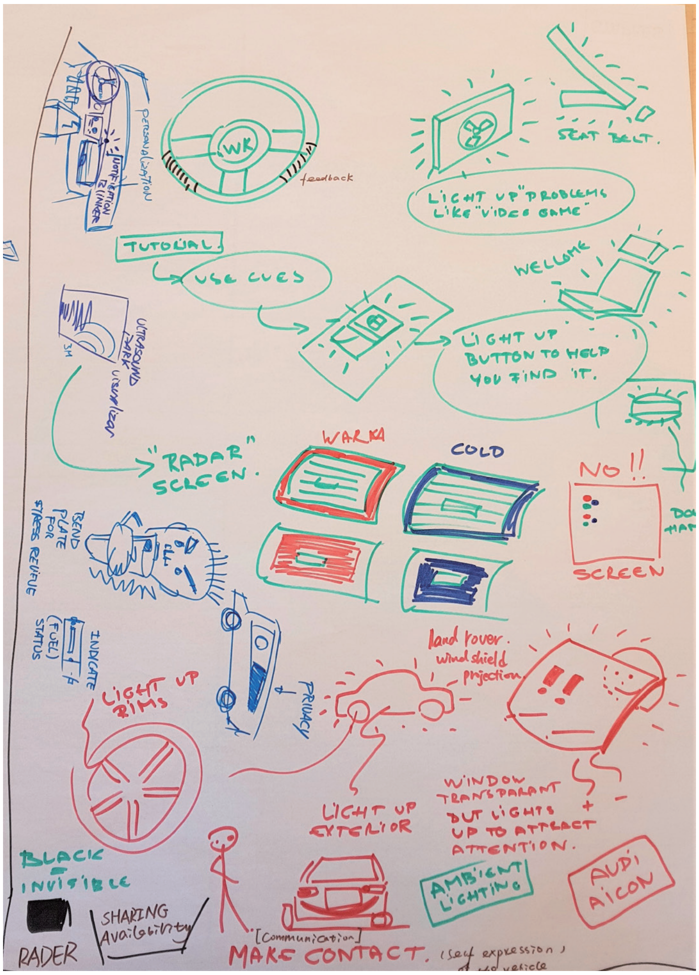



*Figure 18 - Ideation overview*

# SYNTHESIS

The synthesis aims to systematically integrate all the gathered information or conclusions so far into several design directions, among which a design vision will be proposed as the starting point for the following ideation phase.

The process starts with considerations of the current night driving experience, presenting it in the concrete interaction and abstract emotional level separately.  It is followed by the vision of desired driving feelings as the basis for future context. These insights are collected mainly from the driving observation and user interview. The EL properties and automotive trends play a role as the catalyst, which can be considered as a stimulator and enabler to facilitate the transition from the current driving to future context. The visualization can be found on next page.

Based on the logic, seven design directions have been identified, both in interior and exterior aspects.

***Night visibility*** - improving the car visibility at night to indicate its existence to other road users more directly and reliably

***Interaction with the environment*** - making use of EL properties of various activators such as rain and pressure, to allow playful interactions with the outside environment

***Car expressiveness*** - using EL as a medium to contribute the communication between vehicle to vehicle or vehicle to pedestrian

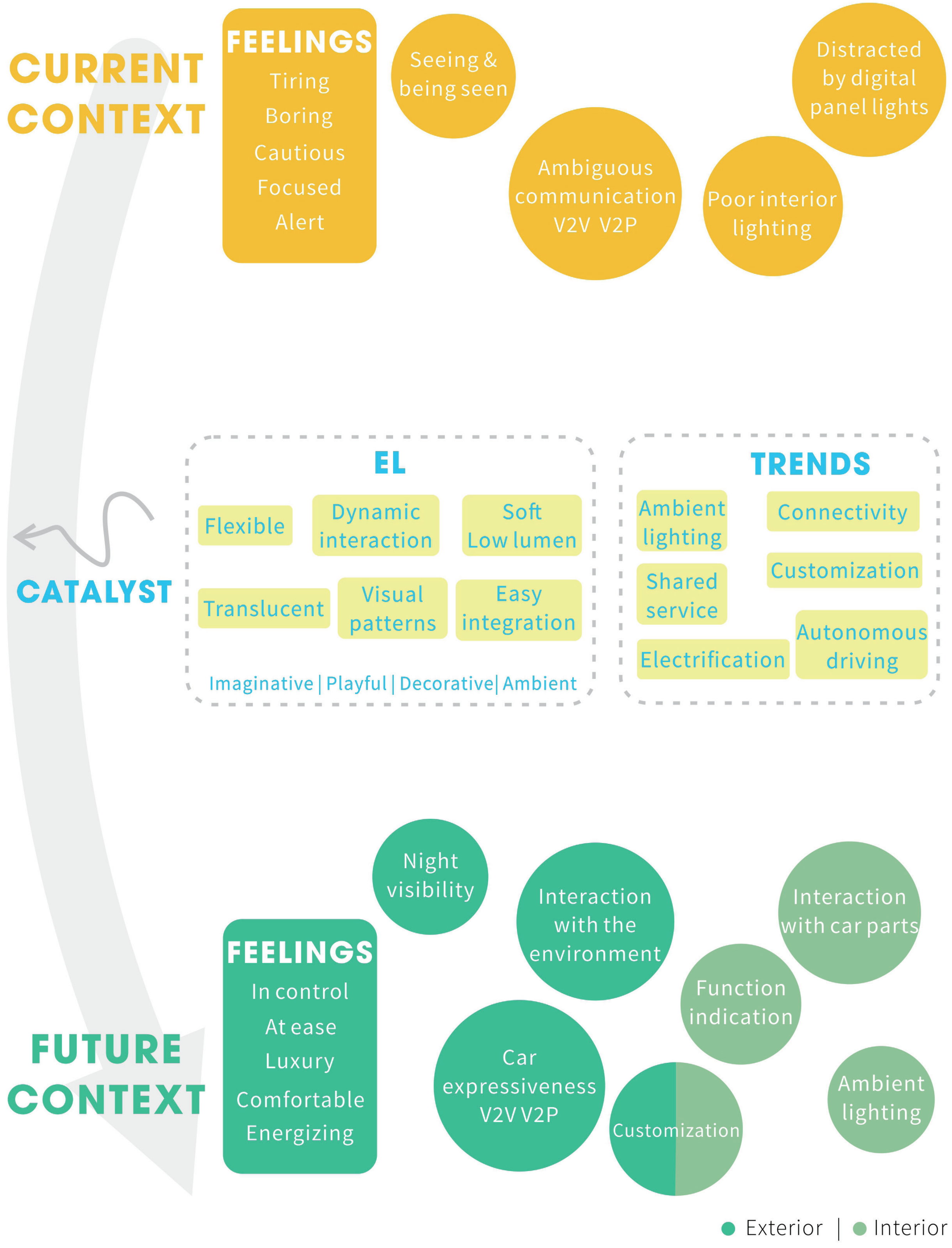
***Customization*** - allowing users to DIY their vehicles freely and easily, both interior and exterior

***Ambient lighting*** -  using EL as a decorative lighting due to its soft lighting output without glare

***Function indication*** - indicating the positions of usable functions such as console and shift gear

***Interaction with car parts*** - creating an interactive experience between driver and car parts, such as steering wheel or safety belt

# SYNTHESIS



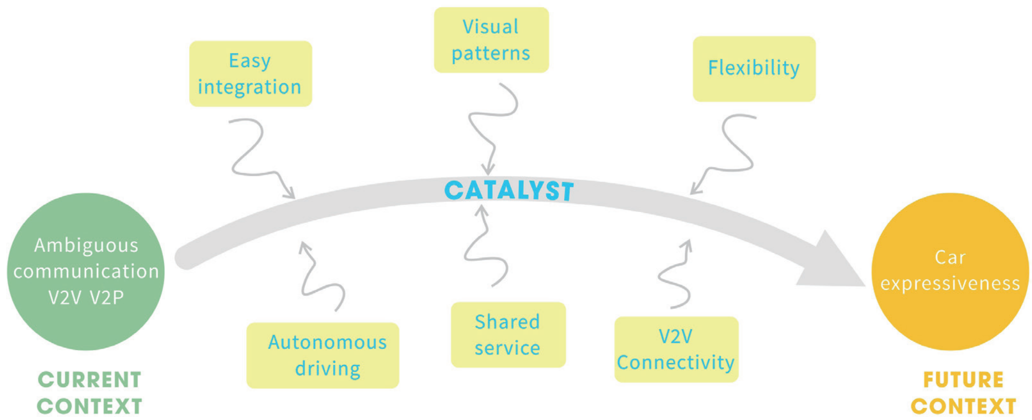
CURRENT CONTEXT
FEELINGS
Tiring
Boring
Cautious
Focused
Alert
Seeing & being seen
Ambiguous communication V2V V2P
Poor interior lighting
Distracted by digital panel lights
CATALYST
EL
Flexible
Dynamic interaction
Soft Low lumen
Translucent
Visual patterns
Easy integration
Imaginative | Playful | Decorative| Ambient
TRENDS
Ambient lighting
Connectivity
Customization
Shared service
Autonomous driving
Electrification
FUTURE CONTEXT
FEELINGS
In control
At ease
Luxury
Comfortable
Energizing
Night visibility
Interaction with the environment
Interaction with car parts
Function indication
Car expressiveness V2V V2P
Customization
Ambient lighting
Exterior | Interior

## Evaluation

To select one promising design direction for the ideation, the weighted objective method is applied. Five criteria are set up with different weighted values, including promising design area, EL uniqueness, practicability, feasibility and trend consistency. The generated design directions are evaluated according to the degree to which they have satisfied the criteria, with the score ranging from 1 to 5.

| CRITERIA / DIRECTION | 5 Promising design area | 4 EL unique | 4 Practicability | 3 Feasibility | 2 Trend consistency | Score |
|---|---|---|---|---|---|---|
| Night visibility | ▮▮ | ▮▮▮ | ▮▮▮ | ▮▮▮▮▮ | ▮▮ | 53 |
| Car expressiveness | ▮▮▮▮▮ | ▮▮▮ | ▮▮▮▮ | ▮▮▮ | ▮▮▮▮▮ | 72 |
| Environment interaction | ▮▮▮▮ | ▮▮▮▮▮ | ▮▮ | ▮▮▮ | ▮▮ | 61 |
| Customization | ▮▮▮ | ▮▮ | ▮▮ | ▮▮▮▮▮ | ▮▮▮ | 52 |
| Functional indication | ▮▮ | ▮ | ▮▮▮▮ | ▮▮▮▮▮ | ▮▮ | 49 |
| Car parts interaction | ▮▮▮▮ | ▮▮▮▮ | ▮▮▮ | ▮▮▮ | ▮▮▮ | 63 |
| Ambient lighting | ▮▮ | ▮▮ | ▮▮▮▮ | ▮▮▮▮▮ | ▮▮▮▮▮ | 59 |

According to the evaluation result, car expressiveness tends to be the best option as the design direction for this project. It is put forward from the current ambiguous communication between vehicle to vehicle and vehicle to pedestrian, especially in cross roads without traffic lights. The supporting trends for the change are the widespread use of autonomous cars, shared service and the popularization of car to car connectivity. These developments make the car expressiveness more urgent and create new demands. EL material can make a contribution, because it allows delicate visual patterns, can be easily integrated on car bodies with high flexibility.



## VISION

**I want to create an interactive and smooth driving experience by facilitating vehicle to pedestrian(V2P) communication at night in a simple but easily comprehensible way.**


*Figure 19 - V2P communication on Toyota concept car i*

# IDEATION

This chapter mainly focuses on the ideation process, to generate diverse solutions for the proposed vision. The design scope is defined and a creative session is conducted. In the end, one concept will be selected for further detailing.

Design scope

Creative facilitation

Ideation

Concept selection

# DESIGN SCOPE

In the design vision, the focus of the project has been stated to be vehicle to pedestrian communication on the road. However, the encountering situations between vehicles and pedestrians have not been explored and specified yet. In this section, it will be defined as ***vehicle to pedestrian (V2P) communication*** in crosswalk scenarios especially for autonomous cars as a representation for the interaction, with analysis of the current context and existing concepts on market.

Traffic is a dynamic and complex system which involves the interaction and communication among various road users, including cars, public transport, motorcycles, bikes and pedestrians. Pedestrians are vulnerable and often the high risk group. There are situations in which cars and passersby encounter in unsignalized zebra crossings or even jaywalk. Drivers, in these moments, are expected to indicate pedestrians that they have been recognized and provide signals whether they can cross or not. According to Färber (2015), the intent communication can be classified into compulsory and informal means. The former refers to regulated car-enabled activities, mainly horn, turn signal, spotlight and headlamp flasher. The interpersonal interactions between drivers and pedestrians directly are called informal means, such as by facial expression or gestures (fig.20).

From the perspective of pedestrians, several factors have been identified to help them decide whether to cross or wait according to the current context. Firstly, they will evaluate the gap distance and driving speed of the encountered car. If it is larger than the safety clearance, they will choose to cross the zebra directly without further consideration. Otherwise, they will wait and observe if the car is slowing down gradually or even come to a complete standstill, occasionally accompanied by eye contact, smile or hand gestures from the driver for further confirmation. Speed, according to a case study conducted by Varhelyi (1998), is stated to be the single factor which is highly relevant to the safety of pedestrians. At night, it becomes more difficult to sense the speed of vehicles and driver behaviours are not so visible. Pedestrians tend to be more cautious and alert in this situation. They will wait until the car stops completely. Headlamp flashing is used as a signal for crossing sometimes by drivers. Frustrating situations usually happen when the expected slowing early and stopping short behaviours are not conducted, which could make pedestrians feel uncomfortable (Mahadevan, Somanath, & Sharlin, 2017). More specifically, when the car has not slowed down early and stopped at a considerable distance, its intention to the pedestrians remains ambiguous and unclear. Examples could be the car gives a sudden stop and the pedestrian is not sure whether he should cross. Or both of them are waiting for reactions from each other, which could be quite time consuming with regard to a dense traffic.

The scope of the project therefore is defined as vehicle to pedestrian communication in crosswalk scenarios, to facilitate the intention expression of cars and crossing judgement of pedestrians. In crosswalk context, decisions are usually made in a very short time. Therefore it is necessary to keep the communication easy and clear to interpret, causing no ambiguity. Pedestrians should be able to judge the next action of the car confidently based on the received signals. It tends to be more natural and smooth to stimulate cues that pedestrians are familiar with and have already adopted in their strategy, including vehicle speed, eye contact, smiles and hand gestures from drivers.

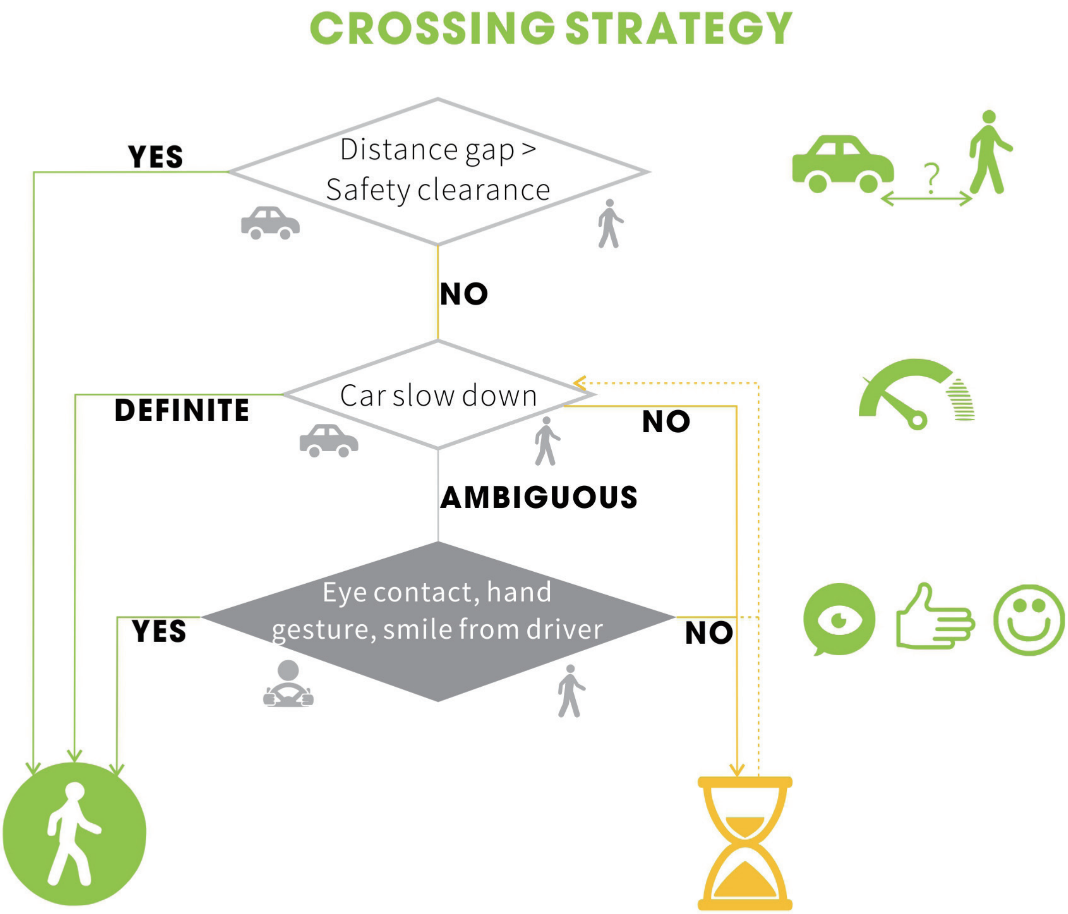



*Figure 20 - Hand gesture from driver*

## Existing V2P communication ideas

Most of the vehicle to pedestrian communication concepts on market are developed for autonomous cars. The gradual maturity and popularity of these cars has encouraged manufacturers to search for new solutions. Drivers will be occupied by other activities and driver-to-pedestrian interaction will be no longer available in the future context. It is very likely that vehicles will be fully responsible for the intent indication. Therefore removing uncertainty in the conversation and finding trustworthy and efficient means to facilitate V2P conversation is a necessary and practical issue, in terms of safety concern and social acceptance. Car manufacturers like Mercedes-Benz and NISSAN have integrated new ways of V2P communication on their autonomous car concepts. The Benz F 015 model (fig.21) has embedded a laser projector in front to display zebra crossing on the road, with its color changing from white to green as a crossing signal. Then the zebra pattern will move towards the estimated crossing direction. Audio messages like “Please go ahead” will be given simultaneously. NISSAN IDS (fig.22) envisions in a different way. It shows intention by displaying messages on the screen in front of windshield and simulates the eye contact through a LED strip on the car body. Other solutions like mimcing eye blinking via headlamp patterns (fig.23) and smiling face (fig.24) have been proposed as well.

*Figure 21 -Mercedes-Benz F 015*


*Figure 22 - NISSAN IDS concept*


*Figure 23 - Smart Vision EQ concept eye blinking*

*Figure 24 - SEMCON's smiling car concept*

# CREATIVE FACILITATION

Creative facilitation(CF) is a collaborative ideation session of a group, in order to solve a problem and generate innovative solutions by means of various techniques. A facilitator will be responsible for planning and leading team members through the session. Considering that the scope of the project has been well-defined, it is valuable to conduct a CF session with other designers or even non-designers for inspiration and idea searching.

## Process

Four participants were invited to the creative session, three students with design background and one from marketing. All of them are quite enthusiastic about automotives and have experience in crosswalk situations. A brief introduction has been given in the beginning, including the target problem and EL lighting properties. The session consists of three main phases, namely problem definition, idea generation and concept development. The goal of the problem definition is to create a common understanding of the proposed problem among group members and to set a specific target for the following ideation. The ideation phase is intended to generate diverse ideas to solve the defined problem and evaluate them. The session ends with concept development, which aims to detail the chosen idea and present it in a comprehensible way. Detailed planning and process can be found in Appendix B.

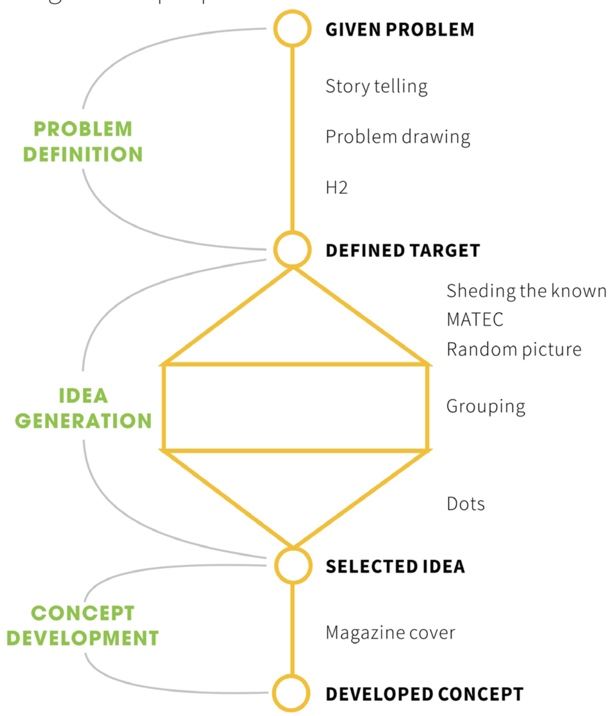



*Figure 25 - Creative session stages*

## Discussion

The generated ideas can be classified into eight categories.


Figure 26 - Idea clustering overview

***Driver intention*** - communicate the intention of drivers via light patterns, smiles, flashed headlamp and projection etc.;
***Pedestrian recognition*** - indicate pedestrians that they have been recognized by the driver, by means of lighting dots, reflection or signal lamp;
***Speed & time*** - visualize the speed and waiting time of the vehicle with dynamic light strips or geometric shapes;
***Message communication*** - display messages to pedestrians directly, suggesting them whether they can cross or not by words;
***Crosswalk*** - integrate the EL lighting on zebra marking as an easy medium for crossing of pedestrians when vehicles are approaching and signaling to the system that they will stop;
***Visibility*** - enhance the visibility of drivers and pedestrians by means of EL wearable applications such as glove or jackets;
***Driver warning*** - raise the attention of drivers when there are pedestrians in front of the car;
***Motivation*** - use EL lights as a way to motivate or reward drivers for their stopping in crosswalk for pedestrians, by fancy lighting patterns or icon filling up.

Most of the solution scope is corresponding to the identified factors that may influence pedestrian crossing behaviours in their strategy, such as the speed of the vehicle, smile and eye contact from drivers. There are various ways to fulfill the intention and awareness communication. Messages, signs and dynamic patterns are the most referred forms in the session. In terms of the applied area, EL lighting shows high flexibility, capable of being positioned on car bodies, windshield, interior, wearables and zebra crossings.

The most unexpected direction is to motivate drivers and show gratefulness for a fancy stopping. One participant has mentioned that when she stops the car in crosswalks, she will expect some grateful responses from pedestrians by nodding, smiling or hand waving. When there is no feedback, she might feel slightly upset sometimes. The emotional need of gratefulness is newly identified and quite inspiring.

For the selected concept “speed indicator" (fig.27), the key meaning team members have proposed is a confident crossing without guessing. By visualizing the vehicle speed via EL lighting in front of the car, pedestrians can judge in advance whether the car has the tendency to slow down and stop for them. Speed is a dominant factor influencing pedestrians’ crossing decisions and therefore an effective cue in the communication. The form of the concept is still to be explored.

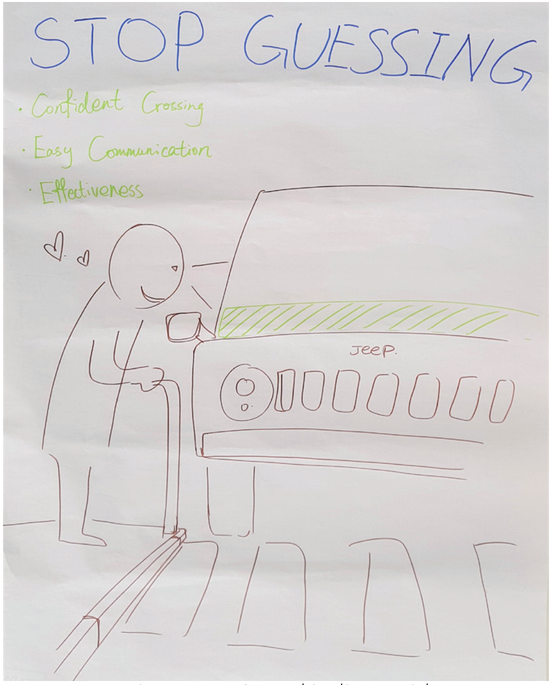


*Figure 27 - Speed indicator idea*

## Reflection

It has been noticed that the generated ideas are not as diverse as expected, partly due to the fact that both design scope and solution approach have been defined in the very beginning through the introduction. It can be beneficial in a way that all ideas will be highly related to the crosswalk scenarios and EL materials. However, this also limits the variations of the insights since too much pre-knowledge and restrictions are presenting in the participants’ minds before creation. I would advise not to include the EL materials in the session or at least not in a very detailed level, but really focus on crosswalk experiences. Later on the facilitator can look for insights from the solution scope and think of possibilities to make these ideas feasible via electroluminescence technology. The other improvement is to plan short breaks or energizing activities reasonably during a long creative session, in order to keep participants fresh and ready for ideation constantly.

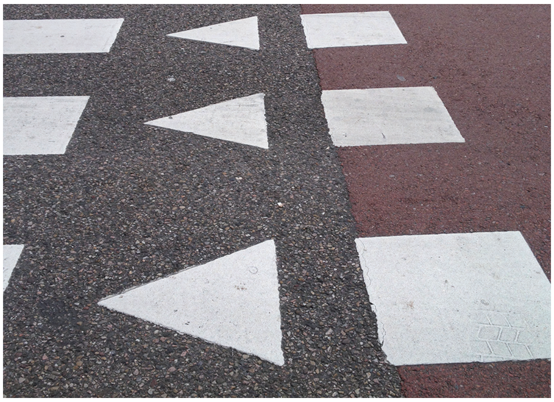
# IDEATION

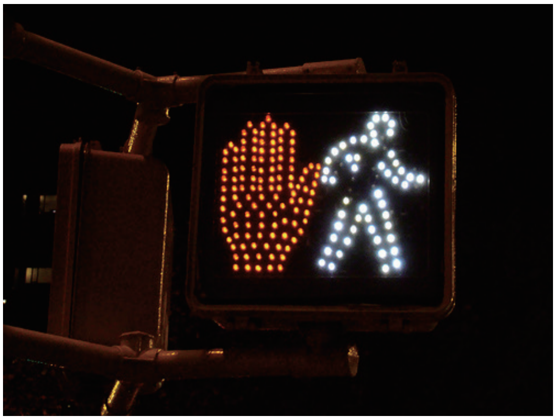
The ideation process is the core part of this phase, which aims to make advantage of all gathered insights so far from the analysis phase and creative facilitation in order to generate rich solutions with respect to vehicle to pedestrian communication in crosswalk scenarios. The creative diamond will be applied as the main guideline, typically from diverging, clustering to the converging process, ending with three selected concept directions for further evaluation.

## Diverging

The main principle of the diverging process is context-driven, which means to really focus on the actual scenario considering current crossing strategies of pedestrians. Several factors influencing the crossing behaviours have already been identified as explained in the design scope section, including speed of the vehicle, interaction with drivers etc. It is valuable to stimulate these aspects by means of electroluminescence as a starting point for ideation. In addition, the surroundings in traffic systems can be inspiring for idea generation as well. There are diverse facilities or signals available which pedestrians are familiar with, such as traffic lights, zebra stripes, road markings and walking signs. These kind of interactions are already widely accepted by the public, therefore its meaning to pedestrians is easy to understand and less likely to cause ambiguity.

The other strategy is to consider what kind of signals pedestrians care about most when encountering vehicles, especially in automated driving context. Variations can be explored in terms of patterns, embedding positions or signal types. In general, as the design scope is defined quite specifically, it is feasible to focus on the real context and use associative techniques in the process.





EL Matrix – Smile
[Mood expression]
[Customization]
zebra crossing.
Moving to the Crossing direction
Crossing Sign
Arrow point to crossing Direction
Waiting for you to cross
zebra + arrow moving
EL Wire
Hand gesture simulation
Toyota Logo Lights UP
AFTER YOU
Message Display.
" blinking eyes " o <
I see U
Speed indicator bar
speed indicator
↳ Speed meter
Car will stop
pedestrian should stop
Road Sign
Car turning direction on Car body.
pedestrian friendly driving.
rise up
slow down
Zebra is eaten ...
footprint on Crosswalk
Pedestrian friendly MEDAL

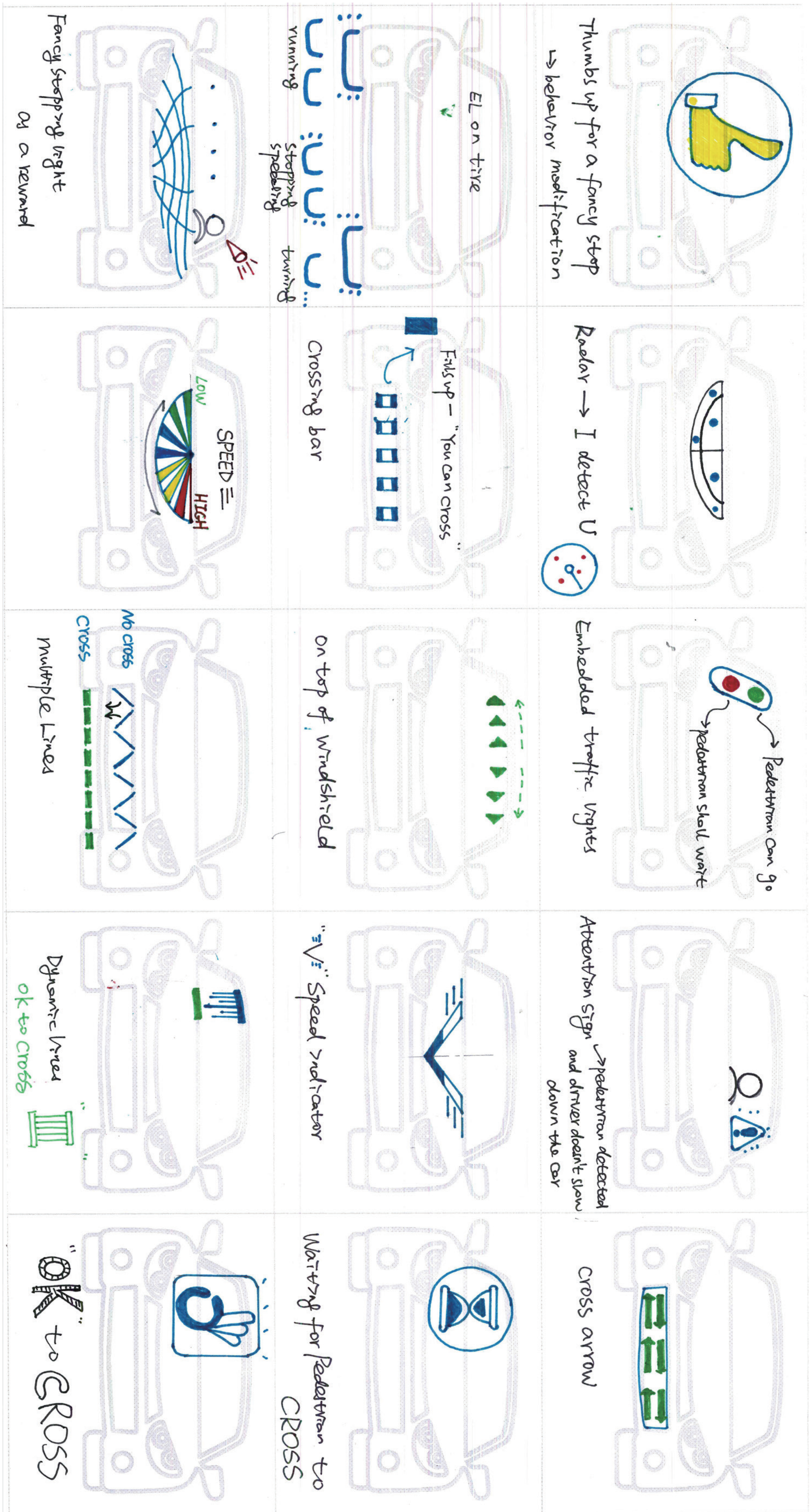



*Figure 28 - Ideation overview*

## Clustering

As illustrated in the overview, all ideas are designed in the form of visual cues. They can be divided into several categories: human-like simulation, symbolic patterns, geometrical shapes and messages. The human-like simulation mainly includes the cues which imitate human behaviours in the context via EL, such as eye blinking, hand gestures and smiling face. The symbolic patterns aim to embed the popular traffic signs to convey the driving intention. Traffic lights, pedestrian walking icon and triangle markings are common examples. It also adopts visual cues which are not typically related to traffic but their meanings are widely recognized, such as the loading signs to express the car status of waiting. The third category is geometrical patterns which generally mean those simple shapes whose meanings are highly context dependent. It requires more effort or attention from users to associate them with the intended information. The message group is to communicate with pedestrians directly via texts on vehicles. Displaying sentences like “after you” or “please cross” is a direct and effective way as well.

These ideas show diverse types of interaction. Most of them are instant and one-time. They function only in the process of encountering with pedestrians. Some ideas are accumulated and continuous, whose status will remain within a longer period. Simply speaking, these visual patterns can remember specific information in the interaction within a period based on which their status can be changed or modified. One example is the pedestrian friendly rewarding sign. It will fill up gradually every time when the driver performs a fancy stopping to pedestrians.

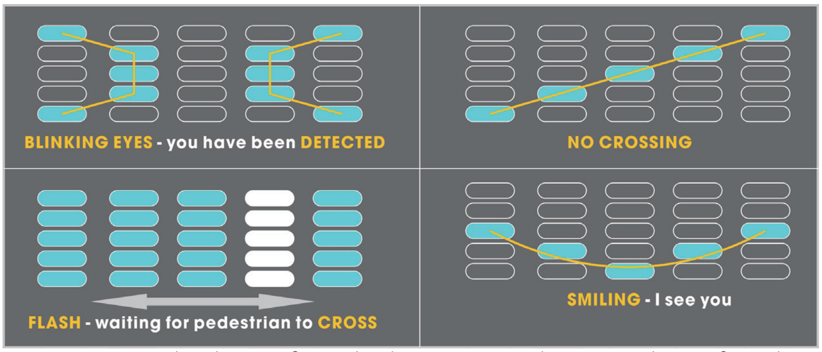
In general, the communicated information includes signaling pedestrians the speed of the vehicle, they have been detected by the car and whether they can cross the zebra srtipes or not. In addition, inspired by the creative session conducted before, EL can be used as a medium to reward drivers for a nice stopping as a way of expressing gratefulness.

## Converging

Evaluating these ideas, three concept directions pop out which are promising to be further developed. The newly launched e-Palette (fig.29) from Toyota is used as a basic model for the ideation indication as suggested by the company during discussion. It is a fully automated multi-purpose vehicle which can be customized for a wide variety of mobility services, such as ride sharing, retailing or working space.

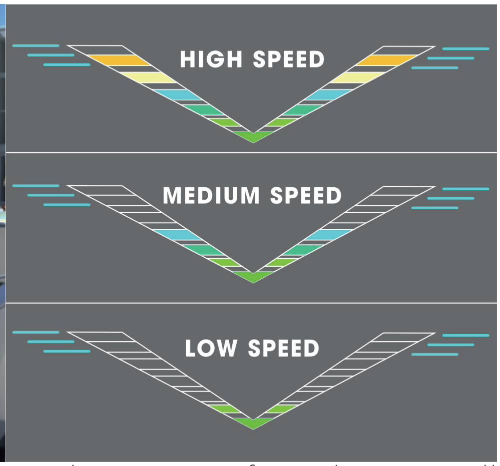

*Figure 29 - Toyota E-palette concept car*

### *Concept direction1 - EL matrix*



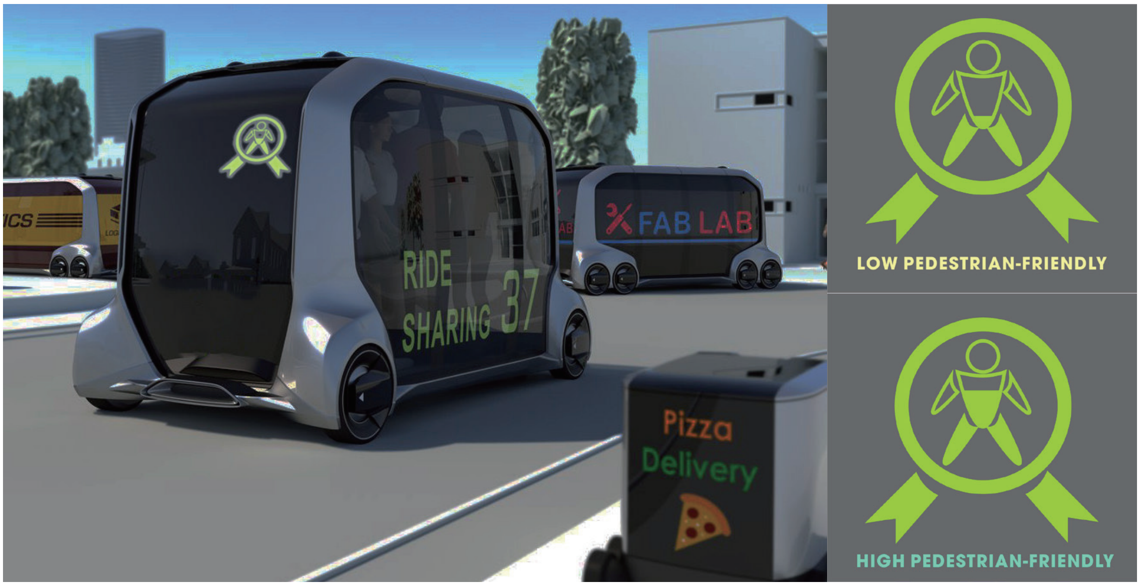

The EL matrix is a universal solution for vehicle to pedestrian communication with which cars can express diverse information in the form of simplistic patterns. The simulation of blinking eyes and smiling face can express that the pedestrians have been detected, which are highly valuable in the context of autonomous cars. They are beneficial to building the trust between vehicles and pedestrians as well. Other example cues can be indicating passersby whether they can cross or not by mimicing the zebra stripes or traffic signs.

### *Concept direction 2 - Speed indicator*


As indicated in the illustration, the EL speed indicator consists of several segments which will light up gradually according to the speed of the vehicle. Also, different colors can function as an extra cue, with green and orange meaning low and high speed respectively. In the human driving situation, this can implicitly influence the stopping behaviours of drivers to some extent. To make the speed transparent for pedestrians will force the drivers to avoid sudden brakes.

## *Concept direction 3 - Pedestrian friendly reward*




The insight of this concept is that drivers usually expect some kind of grateful feedback from pedestrians when they stop nicely, especially in the unsignalized road segments. Therefore, the reward is developed to recognize a driver as pedestrian-friendly based on his stopping behaviours. When pedestrians approach the vehicle, the sign will light up to tell that they have been “seen”. If it is detected that they have the intention to cross, the vehicle will stop gradually and flash the sign as a signal. These interactions are highly relevant to automated cars. However, when the car is in human-driving mode, it will remember the driver's stopping behaviours within a period and the sign will fill up gradually everytime the driver performs a nice stopping. Pedestrian friendliness can be an important factor for evaluating driving skills and habits of car users. Imagining that in the near future, people need to identify themselves for getting access to vehicles and the pedestrian-friendly data can be personalized on the windshield. Extra associations can be linked with social media etc. to enhance their motivation.

# CONCEPT SELECTION

In this section, the proposed three directions are evaluated from diverse criteria and one final concept will be selected for further development. It is necessary to go through the decision making process in a comprehensible way, taking into considerations from different aspects.

***Selection criteria***

*Vision fulfillment* - The concept direction should be able to facilitate the communication between vehicles and pedestrians, either implicitly or explicitly.

*Communication clarity* - The intended information shall be clearly expressed to users without ambiguity.

*Automated context* - The concept need to be applicable and valuable for automated vehicles. This is added because highly autonomous vehicles are in rapid development and it can shape the V2P communication dramatically.

*EL uniqueness* - The concept should be able to present EL unique characteristics compared with alternative lighting technologies.

*Feasibility* - The selected direction is able to be fulfilled and demonstrated with prototypes built by EL materials.

*Innovativeness* - This criterion is to evaluate how new and innovative the concept is, with regard to its form, function, interaction or meanings etc.

The technique adopted to compare the concepts is Harris Profile, which is a visual representation of evaluating alternative choices with various criteria in terms of their strengths and weaknesses. The overview is shown in below.


| CONCEPT | EL matrix | | | | Speed indicator | | | | Pedestrian - friendly | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -2 | -1 | +1 | +2 | -2 | -1 | +1 | +2 | -2 | -1 | +1 | +2 |
| Vision fulfillment | | | ■ | ■ | | | ■ | | | ■ | | |
| Communication clarity | | ■ | | | | ■ | | | | | ■ | |
| Automated context | | | ■ | ■ | | | ■ | | ■ | ■ | | |
| EL uniqueness | | | ■ | | | | ■ | | | | ■ | ■ |
| Feasibility | | ■ | | | | | ■ | | | ■ | | |
| Innovativeness | | | ■ | | | ■ | | | | | ■ | ■ |

For EL matrix concept, its feasibility is weak, because of the challenges to build multiple EL patterns with automatic controlling. In order to convey rich information, it requires far more separate EL lamps than the other concepts. In terms of EL uniqueness, it still needs to be improved to compete or differentiate with other delicate display technologies, such as LED. However, as explained before, its advantage lies in the multi-information by means of combining various patterns, which fits perfectly with the multi-purpose car model e-Palette.

The speed indicator is limited in its expression, which has simplified the controlling of its patterns on the other hand, with only several segments on/off. Considering that it can only communicate car speed to pedestrians, its vision fulfillment is lower than the matrix, which also weakens its fitness into automated driving context.

The pedestrian-friendly reward is the most innovative idea among three concepts. It takes advantage of EL properties of delicate patterns, therefore is more EL unique. However, it can only work when human drivers are in control, which may be redundant for fully autonomous vehicles. In addition, its effect on V2P communication is indirect, mainly on emotional level. That is why it has the lowest vision fulfillment degree, especially with regard to the crosswalking scenarios.

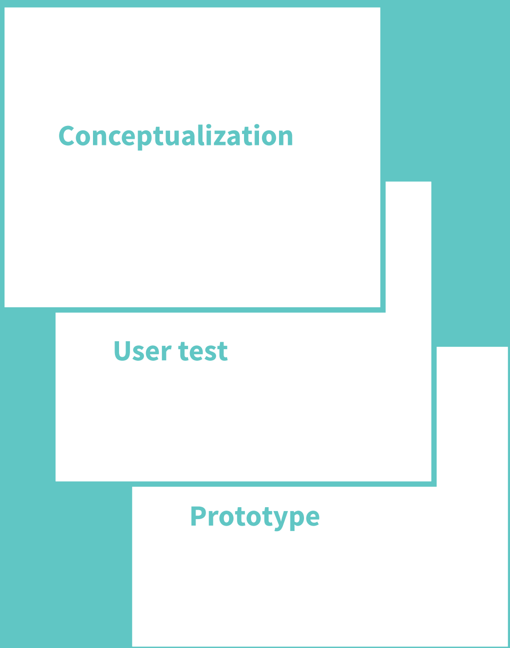
## Concept choice

As shown in the Harris Profile overview, EL matrix slightly stands out compared with other alternative directions. It is capable of expressing rich information with simplistic patterns freely. As far as I am concerned, the EL matrix is more interesting as well, because it is creative to define a lot of aspects, including interaction process, expressed information and visual patterns. Its value does not only reflect in the design result, but also providing insights for shaping the automated driving context.

However, it has to be mentioned that EL matrix does not compete competitive lighting technologies such as LED or OLED in displaying detailed and rich informations. Its patterns need to be further developed so that the visual cues can be simple yet clearly comprehensible by users. Prototype making can be another challenge, to control the matrix displaying desired visual cues. Therefore, the emphasis of the following embodiment design phase will be mainly placed on improving the concept in terms of its expressed information and patterns, as well as demonstrator making.

# EMBODIMENT DESIGN

The embodiment design phase is aiming for further defining the selected idea in terms of its interaction and properties, with a user test session followed to evaluate the effectiveness of the concept. In the end a demonstrator has been built, presenting technical feasibility of the identified key features by hands-on experience.



# CONCEPTUALIZATION

## CO-CREATION

It has been recognized that the current "EL matrix" is still poorly defined in terms of its interaction process, communicated information and patterns. Considering that the main stakeholder - Toyota has not been involved so much in the project yet, it is valuable to arrange a co-creation session with their designers to further develop the concept together. Five designers working on different automotive domains have participated to ensure the diversity of proposed ideas and concerns. The session mainly focuses on the following three topics:

***What*** *- what are the aspects that need to be communicated to pedestrians in crosswalk scenarios?*
***How*** *- how to fulfill the proposed communication by means of EL matrix? In what patterns?*
***Where*** *- where the EL patterns can be positioned on the e-Palette as an indication design?*

It is set up in three phases, starting from context exploration, ideation to concept evaluation. Context exploration means to explore the existing vehicle and/or driver to pedestrian interactions and discuss what information needs to be conveyed to pedestrians, especially in night driving and automated car scenarios. The ideation phase is targeting for the "how" and "where" aspects, generating solutions to specify the EL patterns and embedded areas. These two aspects are highly interrelated and better to be explored simultaneously. The session ends with an evaluation process. All generated solutions are positioned in a C-box with criteria of EL uniqueness and symbolic level to provide a better overview. Participants then choose their favorite ideas and explain the reasons briefly.

## WHAT

In terms of the communicated information in crosswalk scenarios, diverse topics have been put forward. Examples include human driving mode or AUTO mode, pedestrian detection (I see you), car speed (deceleration or acceleration), vehicle stopping or not, pedestrian crossing or not (you can go or not), driver mood (awareness level, in a hurry etc.) and pedestrian status (improper crosswalk behaviours). As shown in the following image, some of them are associated to vehicle/driver, while others are about pedestrian status. The other variation lies in whether they are about emotional aspect or facts display. They have been positioned in a C-box (see fig.30) with these two criteria for better evaluation.


*Figure 30 - "WHAT" information C-box*

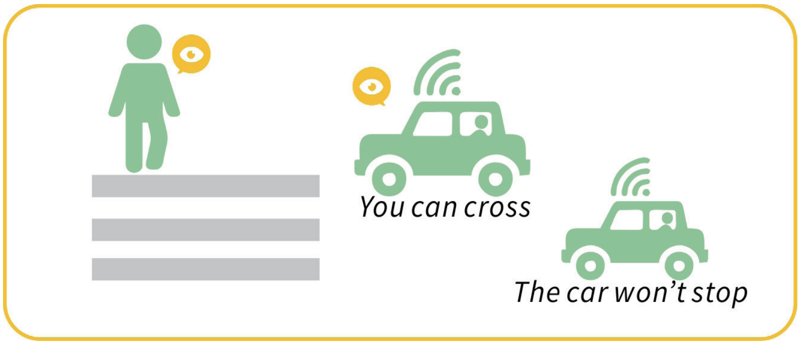
### Vehicle status vs. Pedestrian status

The communicated information can be given from the perspective of vehicles and pedestrians respectively. This concern can be clearly illustrated by the situation to indicate pedestrians that they can cross the zebra. If the cue is showing car status such as it is slowing down and will stop, it is vehicle related. Alternatively, the information can also express that pedestrians can cross. In this way, the car is giving behaviour suggestions to pedestrians.

Both communication perspectives are clear and effective in the context of single vehicle. However, there are situations in which pedestrians have encountered several cars. If one of the vehicle is indicating that pedestrians can cross, this signal might be too dominant. More specifically, it means that the car has fully evaluated the surroundings such as other vehicles status and therefore advises pedestrians that they are safe to cross. Pedestrians may go without further check of signals from other vehicles. In case that an accident happens in this scenario unfortunately, the responsibility remains ambiguous. Therefore, I propose to keep the communication specified to vehicle status, because behaviour suggestion to pedestrians always requires careful evaluation of surrounding environments and further communication with other road users, not only the car's own movement.

**Facts and Emotions**

Emotion and fact communication are not contradictory, but complement each other. Considering that the scope of this project is defined in crosswalk scenarios, facts category is more effective and fits into the context. Emotional expression is interesting as well, but just not highly relevant to the project.




In conclusion, three aspects have been identified to communicate to pedestrians: 1) The car is in AUTO (robot driving) mode or human driving mode; 2) Pedestrians have been detected and it is important to specify the recognized group, such as passersby at left or right; 3) The car will stop or not, which can be represented by deceleration or acceleration. The auto driving indication is a lasting signal, which should light up in the whole autonomous driving period. This is added because users tend to search for different verification cues in human and auto driving mode separately and their crossing behaviours can be varied dramatically. And the deceleration and acceleration signal can be regarded as a more concise and relevant information than vehicle speed itself for pedestrians to make their crossing decisions.

## HOW

Before exploring the patterns and embedded positions, it is important to clarify that the priority of the design is clear and effective communication without ambiguity. Crosswalking is a safety related issue, therefore, the clarity of the visual cues should not be compromised in any situation. Of course, the design should demonstrate the unique properties of EL materials as well, such as seamless integration and delicate patterns.

Though the intended information has been specified, expression patterns can still be highly variable. The pattern categories developed in the session are similar as those in the ideation phase, but more in a matrix style. Human-like expressions are a unique category which can be considered as a natural and effective communication with ambiguity to a certain degree. For example, showing drivers that they have exceeded the speed limit can be fulfilled by attention signal in red. However, a sad face somehow is more powerful than expected as long as its expressed information is clear. Empathy stimulated by human-like icon is influential in changing their behaviours. In the symbolic category, arrow shapes have been frequently used. This is because arrow is a widely accepted icon in daily lives for guiding our attention and movement to its pointed direction and has been adopted massively in traffic systems to communicate route, vehicle movement etc.

One principle is that pedestrians should not be forced to learn extra knowledge in the process of understanding these signals. It is advisable to keep them consistent with visual cues that pedestrians are already familiar with. The other concern lies in the aesthetic aspect which means that the design pattern should fit into the styling of the e-Palette concept car.

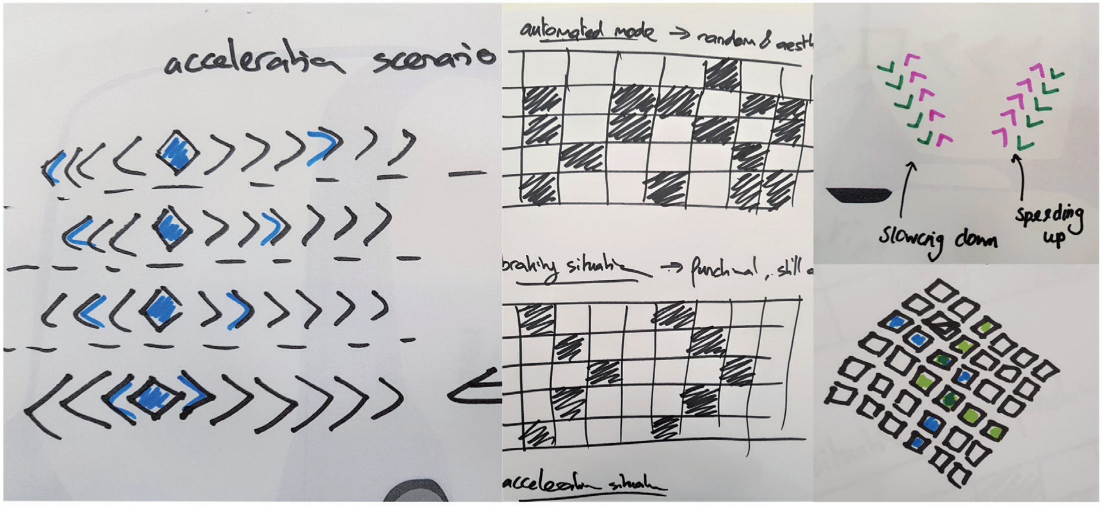


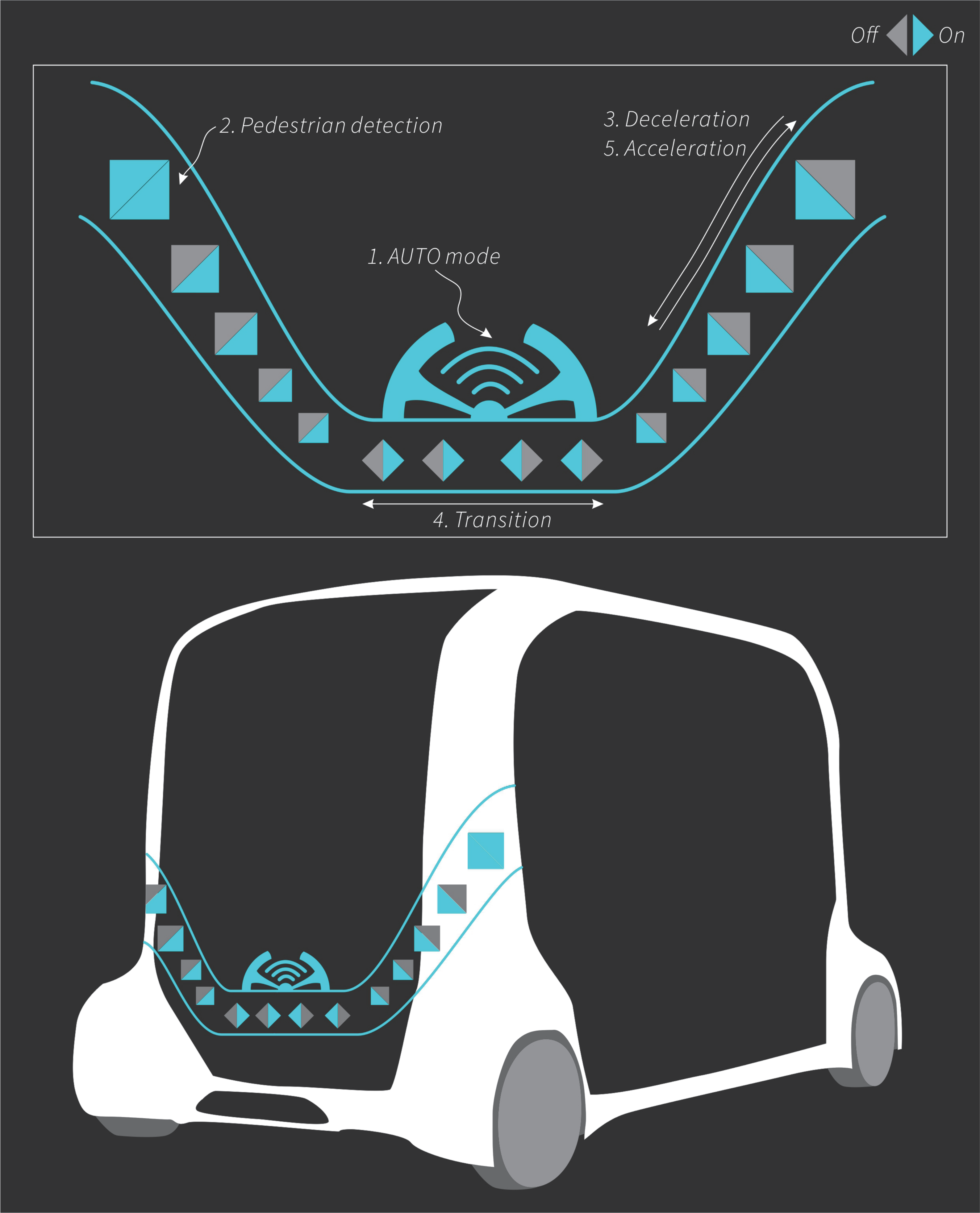

*Figure 31 - Inspiring ideas with arrow shapes*

## WHERE

The position/area of EL materials embedded on the e-Palette is decided mainly by its conveyed information and pattern design. To present the uniqueness of EL, one strategy can be to apply the patterns not only on the car windshield, but also extend it to the metal frame, conveying a coherent impression. In this way, the EL material is differentiate from similar LED displays or flexible OLED panels. Curved surface is a competing advantage as well.

## CONCEPT

As discussed in the previous section, three signals have been decided for vehicle to pedestrian communication, namely auto driving mode, pedestrian detection and vehicle stopping behaviour. With these principles and insights from the co-creation session in mind, the EL matrix has been reshaped and the final concept is presented in the following. Some design inspirations and alternatives can be found in Appendix C.


Off
On
2. Pedestrian detection
3. Deceleration
5. Acceleration
1. AUTO mode
4. Transition

## Design specification

### Triangle pattern

Triangle shapes are the basic patterns of the whole concept. It can be considered as a variation of arrows, which is able to lead the attention of observers to its pointed direction. As discussed in the co-creation section, arrow is a common visual cue in the traffic systems and it fits the design perfectly in terms of speed tendency indication. Various arrow shapes have been developed as the basic elements, both in artistic and geometric styles. Triangle tends to be one of the most simplistic option, which is consistent with the styling of e-Palette itself. One extra benefit is that triangle shape does not consist of thin lines, therefore can be fulfilled by large area application of EL materials, highlighting its capability of seamless integration on substrate materials.

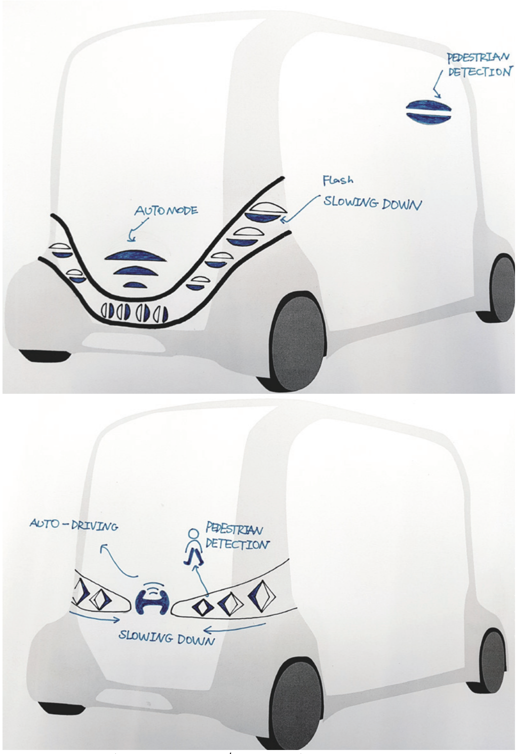


*Figure 32 - Alternative patterns*

### Auto mode

The auto driving mode means to have the automated system taking control of the vehicle instead of traditional human operators. This indicates full handling of the car, including awareness of the surroundings such as other vehicles, pedestrians, traffic signs, road conditions etc., as well as navigation of the vehicle. Human drivers will be responsibility free with regard to high level autonomous vehicles. The evident features associated with auto driving mode can be constant surrounding detection and hand off navigation. Therefore, it is visualized by a simplistic steering wheel and sensing icon. Dynamic effect is added to the latter by lighting up the three curves one by one, emphasizing its continual communication with the environment.

*Figure 33 - Auto driving mode features*

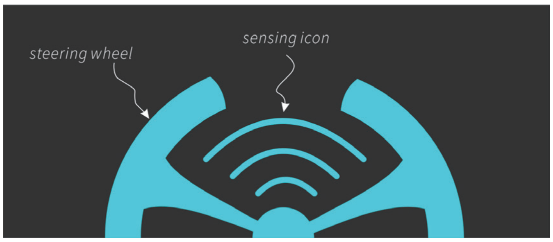


*Figure 34 - Auto driving visual cue*

### Deceleration & acceleration

Deceleration and acceleration of the vehicle is communicated by the pairs of diagonally distributed triangles. The vertical variation is specially added to visualize that the speed of the vehicle is lowering down and rising up, by means of down and up arrows. This also avoids the ambiguity that the car might be indicating it is turning directions or giving crossing suggestions when the triangles are placed horizontally.

When the car is slowing down, these downward triangles will light up from top to bottom one by one. While speeding up, the upward icons will glow in the opposite manner. As illustrated in Figure 35, the size of the triangles varies as well, which is consistent with speed tendency of the vehicle. More specifically, when the car's speed is lowering gradually, the exact luminous triangle gets smaller as well to enhance the signal.

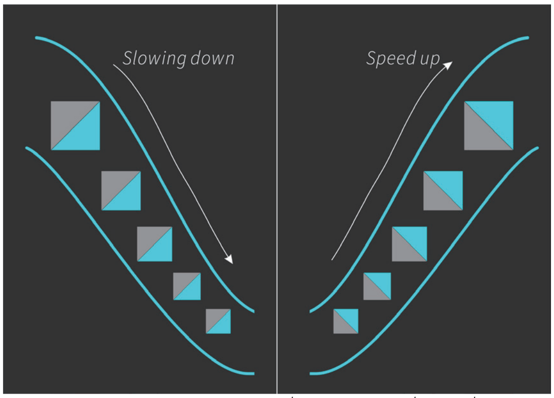


*Figure 35 - Deceleration and acceleration*

### Transition

The transition (fig.36) is designed as a pre signal to indicate car status shiting from slowing down to speeding up. Meanwhile, the car will stay still, waiting pedestrians to cross. The transition cues are placed in a horizontal line, ensuring other road users that the car is in a stable state and will not move currently. When the inward triangles light up, it means the car has slowed to complete stop. While pointing outward, it means the car will start soon. Other road users should be cautious about that.

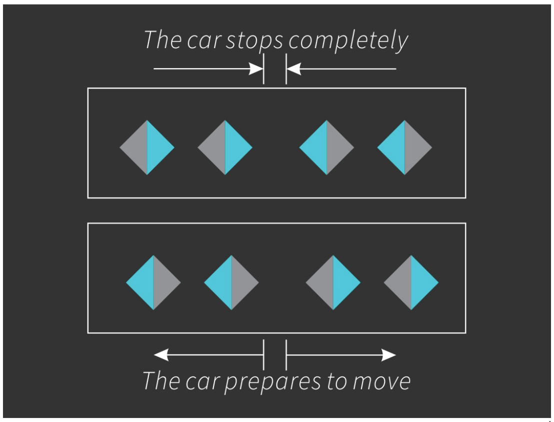


*Figure 36 - Transition signal*

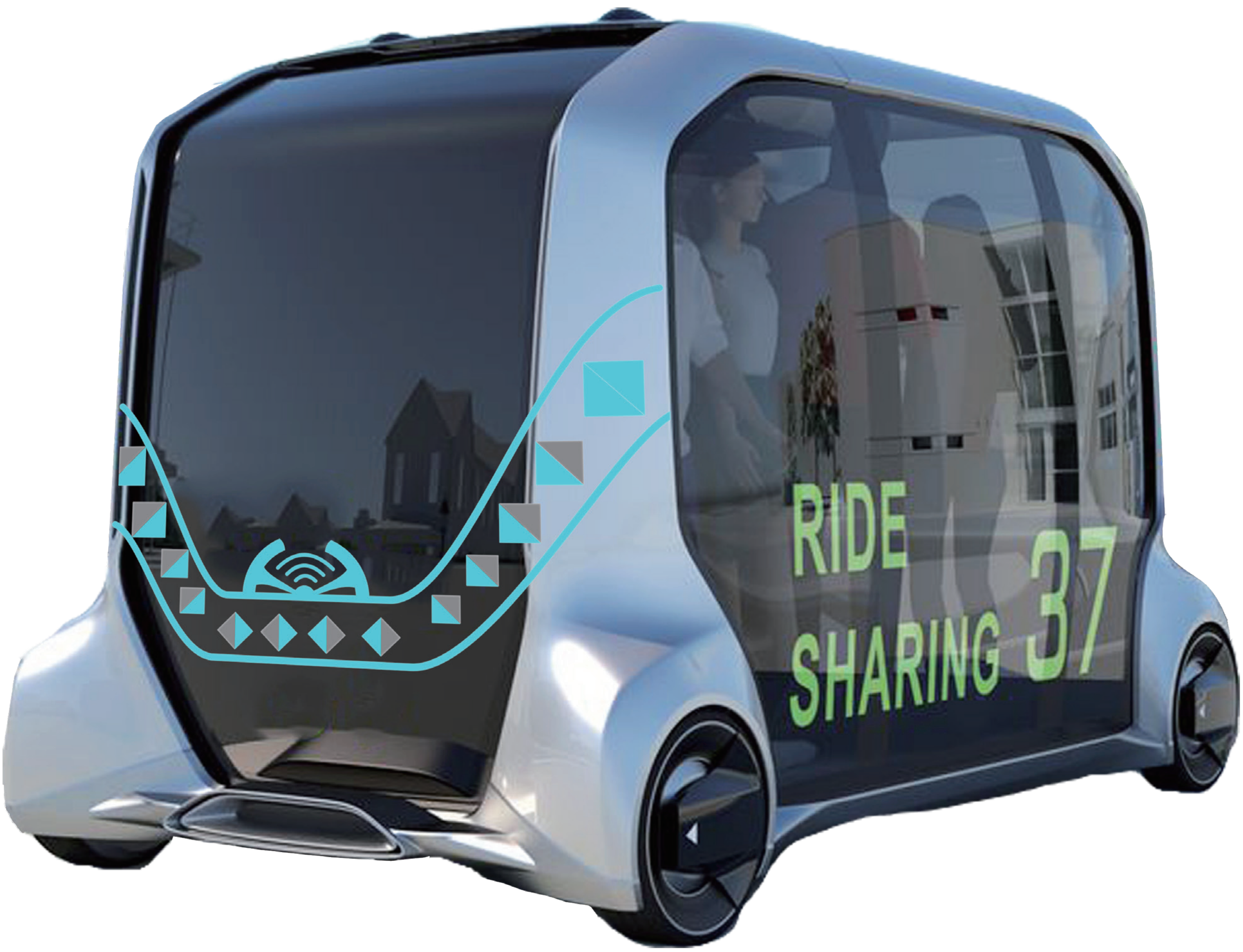
### Pedestrian detection

Pedestrian detection is signalized by flashing the pair of triangles (square) exactly in the direction of the pedestrian two times. In the situation of encountering multiple pedestrians, it is necessary to categorize them and give visual cues separately. On the other hand, adding more elements in the design might be an extra burden for pedestrians regarding their crossing behaviours which normally happen in a relatively short time. Therefore, I propose to make advantage of the current visuals but differentiate its communication by means of dynamic effects and pattern combination. Specifically, a pair of triangles can be combined to a square pattern and flashing effects are added to highlight the signal.

It is worth mentioning that the concept is an early exploration of vehicle to pedestrian communication for autonomous cars. Public perceptions on these vehicles in the near future are still unknown and the level of trust in between can affect the design and actual interaction process. For example, if the public shows high confidence in the automated system, the validation or cues they need for crossing behaviours will be less. In this case, pedestrian detection itself might already be enough as the necessary signal. Or even none cues are needed anymore since the public believes the reliability of autonomous cars. Also, it can influence when pedestrians start to cross. For cautious groups, they tend to wait until the car completely stops. While others might start to move as long as the car gives signals of deceleration.

### Toyota benefits

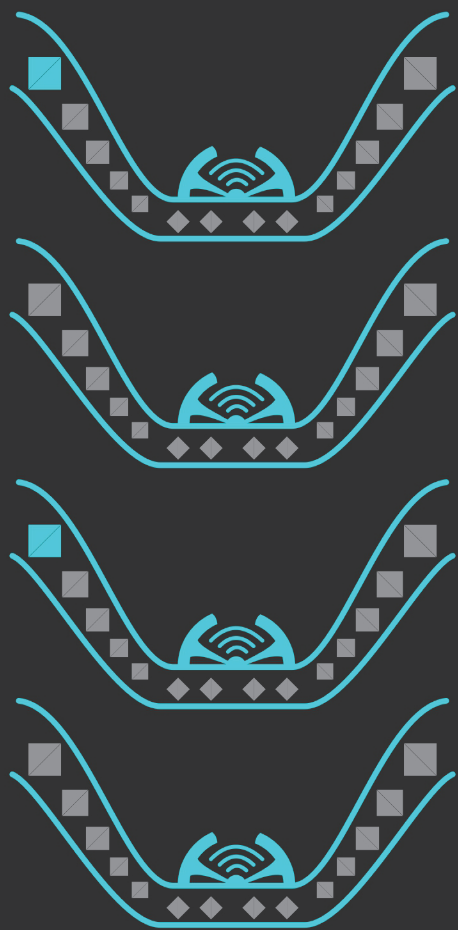
For Toyota as a leading automotive manufacturer, this kind of vehicle to pedestrian communication is an inevitable concern with the advances in automated driving technologies. The public acceptance of autonomous cars can be influenced significantly not only by the technical improvement but also by the interactions they can have with these cars, which should be able to secure the vulnerable pedestrians. Therefore, to gain popularity among customers, this issue needs to be targeted on. The other main benefit of the concept is focusing on safety. This is always a top priority of Toyota's mobility experience. With the visual information added, there will be less ambiguity for both drivers and pedestrians in crosswalking scenarios, which can contribute to creating a safer mobility environment. In addition, the design can help to differentiate Toyota cars from other competitive vehicles in an obvious yet low-cost way from marketing perspective. More selling points can be expected such as user customization, adds-on components and services etc. varying on the current patterns.


RIDE
SHARING
37

## INTERACTION PROCESS

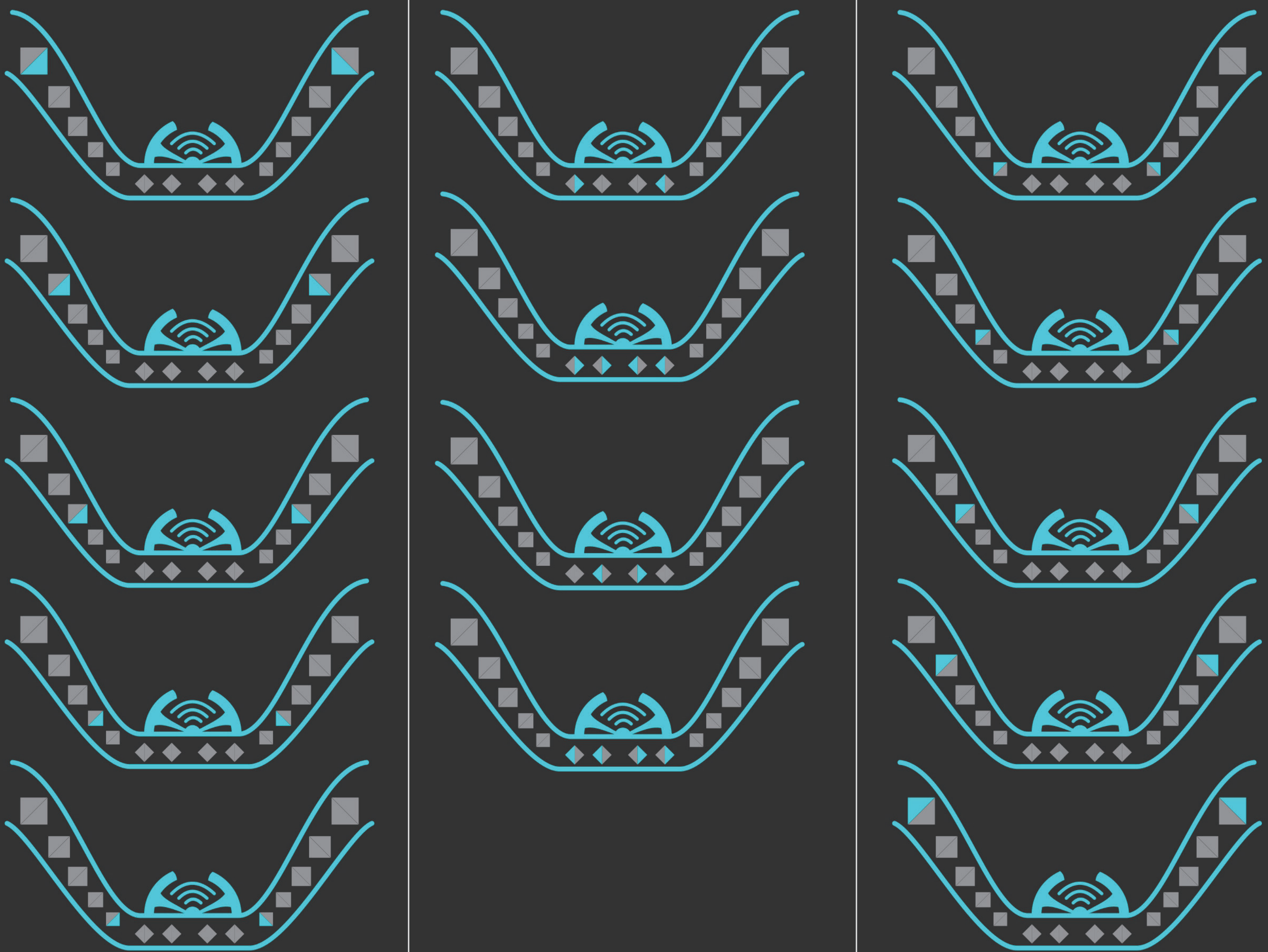
With regard to automated cars, the vehicle to pedestrian communication in crosswalk scenarios is divided into five stages, as illustrated in the following pages.

| AUTO MODE STAGES | AUTO Mode | Pedestrian Detection |
|---|---|---|
| VEHICLE | 1) The car shifts from human driving mode to AUTO mode. | 2) The car detects a pedestrian in front waiting at zebra crossing and signals that he has been seen. |
| PEDESTRIAN | 1) Pedestrian notices that the car is in auto driving mode. | 2) Pedestrian looks at the car and notices the flash signal from his direction. |
| VISUAL CUES | 1) The Auto driving sign lights up with sensing icon flashing. | 2) The pair of triangle icons flashes two times in the pedestrian direction. |



*On* ◀▶ *Off*

| Deceleration | Waiting | Acceleration |
|---|---|---|
| 3) The car slows down gradually. | 4) The car stops completely.<br>5 )The car is ready to restart. | 6) The car speeds up again to continue the trip. |
| 3) Pedestrian knows the car is giving a brake for him and prepares to cross. | 4) Pedestrian crosses the zebra.<br>5) Pedestrian knows the car will move soon. | 6) Pedestrian walks away from the car. |
| 3) The down arrows light up one by one . | 4) The inward triangles light up .<br>5) The outward triangles light up . | 6) The up arrows light up one by one . |



In terms of the human driving situation, the interaction process changes slightly. At daytime, the communication can be fulfilled by drivers using hand gestures, facial expressions etc. Therefore, the design will mainly function at night or in dark ambience when driver behaviours are not visible to pedestrians anymore. It plays the role as a facilitator between drivers and pedestrians to make sure there are common understandings between them. For drivers who still take control of the car, two signals will be shown to them in the crosswalking scenario as assistive information, namely pedestrian detection and readiness to speed up, based on the vehicle's sensing feedback. While for pedestrians and other road users, they will be informed of deceleration, waiting and acceleration of the car.

## HUMAN DRIVING MODE

| STAGES | VEHICLE | DRIVER | PEDESTRIAN |
|---|---|---|---|
| **Pedestrian Detection**  | The car senses a pedestrian in front and indicates the driver. | The driver notices the signal and is aware there are pedestrians nearby. | The pedestrian sees the car and wonders if he can cross or not. |
| **Deceleration**  | The vehicle is slowing down. Deceleration cue lights up automatically to the pedestrian. | The driver is braking to let the pedestrian cross first. | Pedestrian sees the deceleration signal and knows the car starts to slow down. |
| **Waiting**  | The vehicle stays still.<br>The vehicle senses there is no passerby and indicates both the driver and other road users that it prepares to move. | The driver stops the car and waits.<br>The driver sees the signal and prepares to start the car. | Pedestrian crosses the zebra marking.<br>Pedestrian knows the car will move soon. |
| **Acceleration**  | The car starts to move. | The driver speeds up the car gradually and continues his trip. | Pedestrian walks away. |

# USER TEST

This research is conducted to evaluate the proposed concept from the user standpoint. One key quality of the design lies in its meaning clearness to pedestrians, which means that users can easily understand these visual cues without ambiguity in crosswalking scenarios. In addition, assuming the communication between car to pedestrian is smooth, its effects on their crossing behaviours still needs to be evaluated. The effectiveness can be checked in terms of crossing moments and feelings in the abstract level. Therefore, a user test session is necessary to gather feedback on the design with regard to these recognized aspects.

## Research questions

Two main research questions have been proposed as following:

*"How clearly these visual signals can express their meanings to pedestrians?"*

*"How the concept will influence pedestrians' crossing behaviours? In which way?"*

## Method

The session starts with an introduction of the whole concept to participants. It includes context explanation - vehicle to pedestrian communication in crosswalking scenarios, design specification - design elements, and a GIF image to simulate the dynamic effects of the visual cues as a vivid presentation.

After that, a semi-structured questionnaire has been set up to gather information about user perceptions on the design, specifically about its clearness and effects on their crossing behaviours. One interesting comparison among these questions is to ask participants when they will start to cross in auto-driving mode and human driving mode respectively and explain the reasons behind their decisions. This is added to explore the possible interactions and how user attitudes towards vehicles in different modes can influence their crossing occasions.

*Figure 37 - Key moments of the GIF Simulation*

## Results and discussion

In total, five participants have been invited for the user test, with their detailed replies shown in Appendix D.

### Communication clarity

The whole concept in general, has gained positive feedback in terms of communication clearness, with an average 3.8 out of 5 (definitely clear). The most confusing part is the pedestrian detection signal, which can be mistaken for turning signals. This is because users cannot easily relate it with "I see you" messages. Improvements can be achieved by using more round shapes or eye-like simulation to strengthen the association and differentiate from normal lamps. For the deceleration and acceleration expression, participants think it's quite clear and logical to understand, due to the up-down flow and visual forms. One interesting perspective is that the dynamic effects can give the impression that the car is breathing in and out as humans. With regard to the blue color, it has been rarely used on vehicles yet, therefore can indicate observers unconsciously that there might be new forms of communication. It needs to be taken into consideration that the meaning of these visual cues is highly dependent on the vehicle movements such as its speed and status, which has not been expressed in the GIF yet. Therefore, the effects of the communication in real world scenarios might be better than the simulated results.

### Crossing occasions

As stated in the concept detailing, crossing occasions of pedestrians can vary significantly due to their personalities and attitudes towards vehicles in different modes. In the user test, this assumption has been further validated by asking participants when they will choose to cross the street encountering autonomous and traditional vehicles separately. As expected, their answers do show differences. In general, most of them would like to cross when the car almost or completely stops in auto driving mode. They have stated that they need to make sure there is no risk at all in the situation due to lack of trust in these cars for now. While if the vehicle is controlled by human drivers, they tend to cross earlier, such as in the beginning of deceleration. The reason is that they believe in human drivers, not in driving skill aspect but more in emotional level, to assume they won't be hit consciously.

### Concept value

In the questionnaire, participants have been asked about the influence this design can have on their crossing behaviours. In the functional level, it enables the communication between vehicles and pedestrians, especially in terms of the auto driving system. By means of these conveyed information, pedestrians can cross with more confirmation and certainty. In the current situation, human drivers and pedestrians are talking in a subjective and emotional way, which can cause misunderstanding or guessing each other intentions. The concept can help to eliminate the confusion in between so that they can make the decision without extra thinking. In the emotional level, most participants feel more secure in the crosswalking process. One participant mentioned that it can help to build trust in these autonomous cars since he is updated and aware of the vehicle status. In this way, the vehicle movement can be predicted.

## Conclusion

Reflecting on my design vision and research questions, the concept is presented in a simple way with considerable level of comprehensibility. Most of the visual cues can be clearly understood without extra effort. With regard to effectiveness, it does make a difference to pedestrian crossing behaviours by informing them the vehicle's intentions, especially for highly autonomous cars. Both drivers and pedestrians can be free from guessing each other's intentions and therefore enjoy a smooth experience. However, as an early exploration of vehicle to pedestrian communication, further tests need to be conducted on specified groups in real-life context, such as children and people with color blindness etc. to validate the design more detailed.

# PROTOTYPE

The goal of the prototype building is to demonstrate technical feasibility of the concept. Two properties have been recognized as crucial for the design and therefore need to be experimented on: 1) EL lamps can be printed on curved surfaces, with metals and glasses as substrate materials separately; 2) The lighting of each pattern can be controlled automatically, by coding for example, to guarantee the desired animated effects are applicable. Considering the goal of the prototype and time limitation, it is slightly infeasible to build the whole design on the e-Palette concept car. Therefore, the prototype is simplified to the following scheme, building pair of the triangle patterns on both curved metal and transparent plastic plates. It can be noticed that plastic has substituted for glass substrate material, because bending glasses requires specificilized facilities and techniques which cannot be achieved easily with the current resources. Plastic seems to be an acceptable alternative for its wide availability and easy processing on the condition of similar transparency.

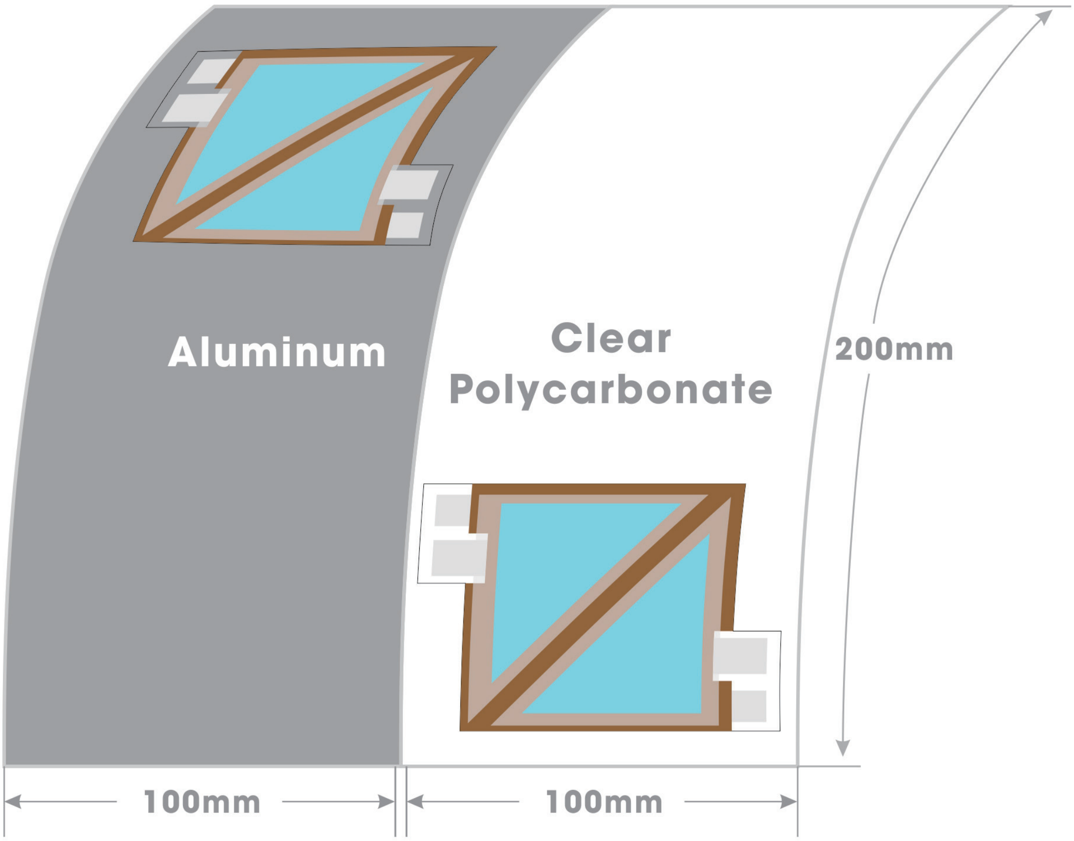



*Figure 38 - Prototyping scheme*

# SCREEN PRINTING

## Substrate

The first step of the prototype is preparation of the substrate materials for the following screen printing. The aluminum and polycarbonate sheets have been cut into desired dimensions 100*200mm and need to be bent into curved surfaces. For the aluminium, this can be fulfilled easily by means of a roll forming machine. While deforming polycarbonate requires heat to soften it and a mould to shape into desired curvature. In this project, the approach is to clamp the plastic plate between two already curved aluminium substrates and place them together into an oven, heating at temperature 140 degrees Celsius for about 40 minutes. In this way, the plastic can be formed into the same curvature as aluminium when cooling down. The specific temperature is chosen based on various heating tests with its glass transition temperature - 147 degrees Celsius as a reference.

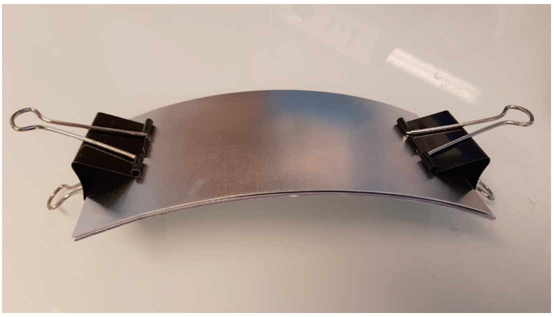


*Figure 39 - Polycarbonate forming method*

## Layering scheme

A scheme has been created to explore how the different layers of inks can be designed and deposited on top of each other, as well as how to connect the electrodes to the power source. Example concerns include that the dielectric pattern shall be bigger than any layers to avoid the occurrence of short circuit. And connection bars have been added for convenience. The layering scheme has been adjusted several times learning form practice, and decided as following.

As shown in the fig.40, an extra isolation layer is added compared with traditional EL structures. It is mainly for separating the rear electrode and conductive aluminum substrate to avoid short circuit. The specific electroluminescence materials used in the screen printing is shown in Figure 40. More detailed explanation can be found in Appendix E.

Isolation layer - Dupont dielectric 7165 for aluminum substrate only

Rear electrode - conductive silver paste

Dielectric layer - barium titanate (white)

Phosphor layer - high brightness phosphor ink (blue)

Top electrode - PEDOT:PSS

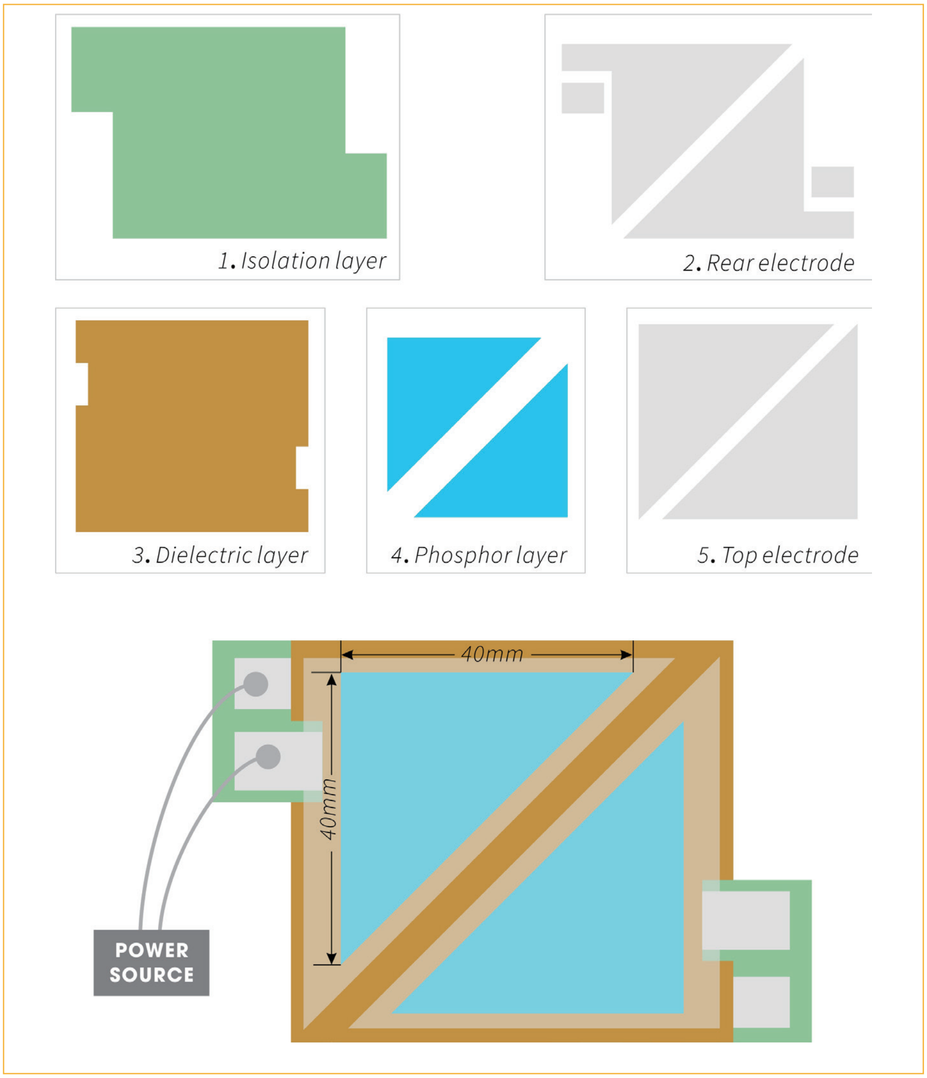



Figure 40 - Screen printing layering scheme

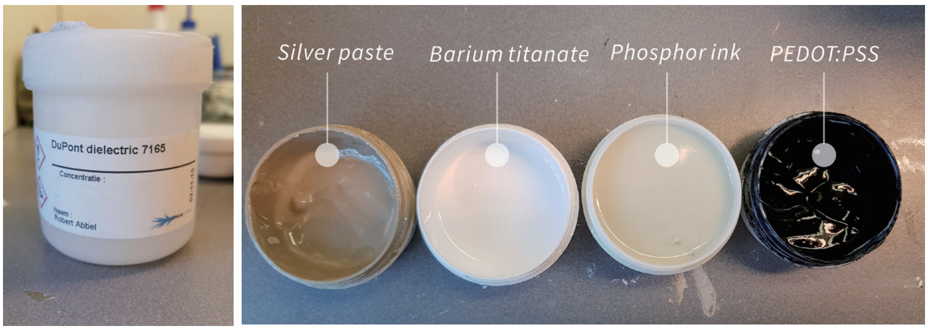



Figure 41 - Screen printing inks

### Printing

The basic principle of screen printing is to deposit layers of inks on a substrate by pressing through a mesh. The patterns of the applied inks can be controlled by blocking part of the mesh so that inks can pass through only in the open area. This can be fulfilled easily by a vinyl plotter which is able to cut out designed vector shape from vinyl sheets.

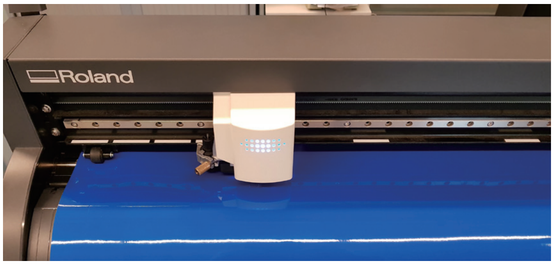



*Figure 42 - Vinyl plotter*

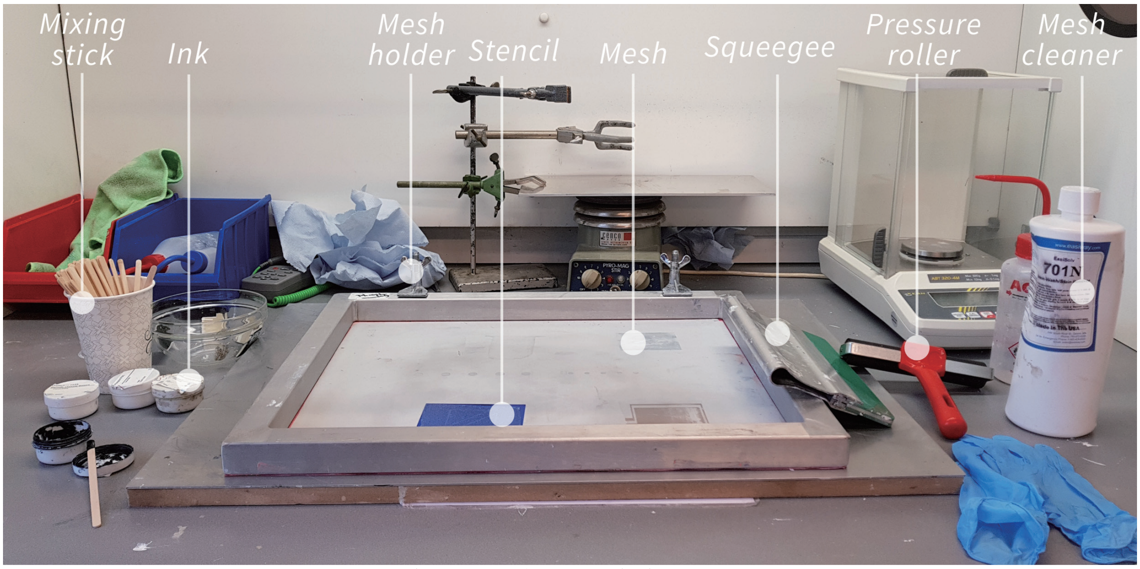



*Figure 43 - Screen printing setup*

The screen printing process goes like this in general:

1. Preheat the oven to 140 degree Celsius for Aluminium and 50 degree Celsius for polycarbonate respectively
2. Fix the mesh on the meah holder
3. Place the plotted stencil on the mesh with a pressure roller and fix the substrate under the mesh after precise alignment
4. Mix the ink and place small amount of it on the vinyl
5. Use a squeegee to push the ink through the mesh and try several times if needed, especially for dielectric layer
6. Collect the left ink if there is any and close it immediately after use
7. Take out the substrate and place it in the oven, heating 15 minutes for Aluminum substrate and 30 - 40 minutes for polycarbonate
8. Clean up all facilities, especially the mesh
9. Repeat the procedures 3 - 8 until all inks are applied

In the fabrication process, two issues need to be discussed in detail. Firstly, the substrates are curved surfaces instead of flat ones. This makes it difficult to fix it and apply the inks evenly. One way is to add extra weight on the frame of the mesh so that the substrate cannot move easily under pressure. It also helps to increase the contact area between them for better ink application. This works perfect for all inks except the PEDOT:PSS, partly because PEDOT is very thin and cannot stick well on other layers. When lifting the mesh, patterns can be seen frequently.

The other concern comes from polycarbonate. When placing it in the oven for curing the inks, the material experiences observable thermal expansion. In the process of gradual cooling down in the open air, it contracts slightly, leaving cracks on the ink layers (see fig.45). Therefore, common curing temperature 140 Celsius degree will not work. Through tests under different temperatures, it has been found that 50 Celsius degree with 30 minutes curing is an acceptable option, presenting reasonable even surface. In addition, Polycarbonate(65) has far higher thermal expansion coefficient than glass materials (6), therefore it can be assumed safely that this phenomenon will not happen when the inks are applied on glasses as proposed in the concept.

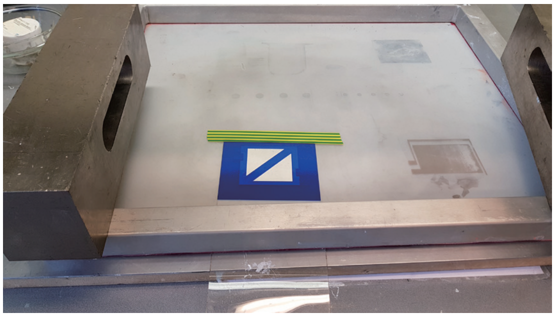


*Figure 44 - Adding weigh to fix substrate*

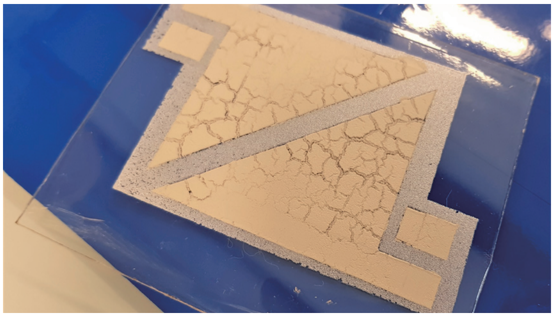


*Figure 45 - Silver cracks cooling in the air*

## ANIMATED EFFECT

The other key property of the concept is recognized as controlling of each EL lamps autonomically. Traditionally, an inverter is manually controlled to manipulate the lighting of its connected EL. This tends to be inconvenient in terms of controlling multiple lamps and involvement of other electronic components such as sensors for building up more advanced systems. In this project, the solution is to use an EL Escudo Dos shield which is able to control up to eight EL lamps via its EL channels.

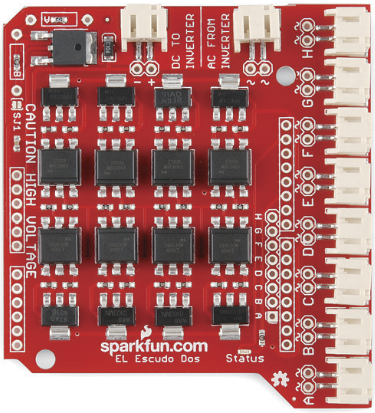


*Figure 46 - Sparkfun EL Escudo Dos*

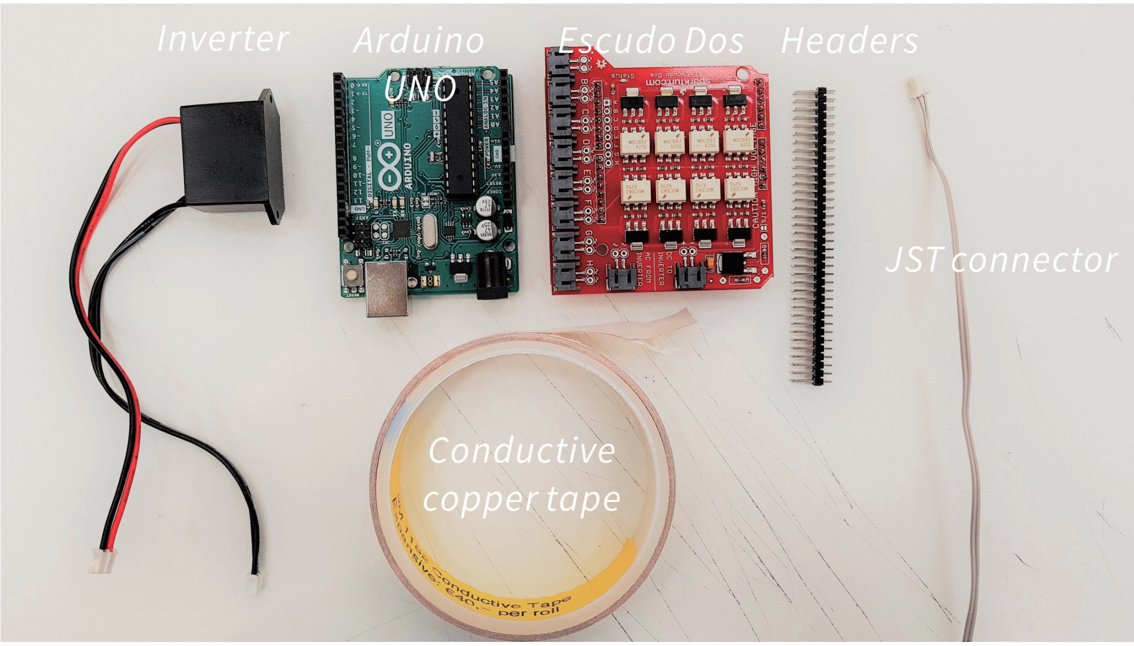



*Figure 47- Components for lighting system*

To set up the system, an Arduino board, an Escudo Dos shield, an inverter, multiple JST connectors, Arduino headers and conductive copper tape are required. The first step is to solder the EL shield onto the Arduino board with headers. Then an inverter needs to be connected onto the shield to supply the desired high voltage AC power source. Detailed tutorial can be found in Sequencer & Dos (2018). These JST connectors need to be inserted into the eight EL channels. The other end of them are naked wires, which will be attached on the silver connection bars of EL lamps with copper tape.

When the four EL lamps are connected separately to the Escuso Dos channels via JST wires, they can be programmed easily. The eight EL channels labeled “A” through “H” on the shield, are linked to digital pins “2” through “9” of Arduino board, therefore, lighting up of each lamp can be controlled simply by command “pinMode (pin, HIGH);”. In the prototype, the animated effect of lighting one by one and pairing have been simulated as a representation.

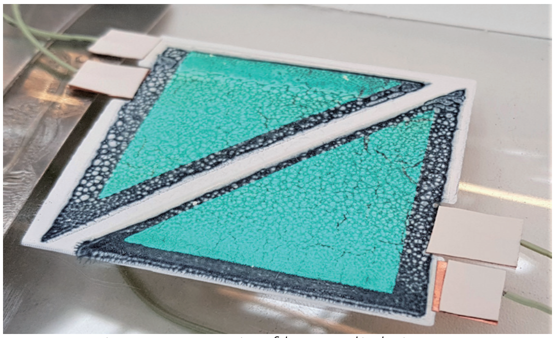


*Figure 49 - Pair of lamps lighting up*

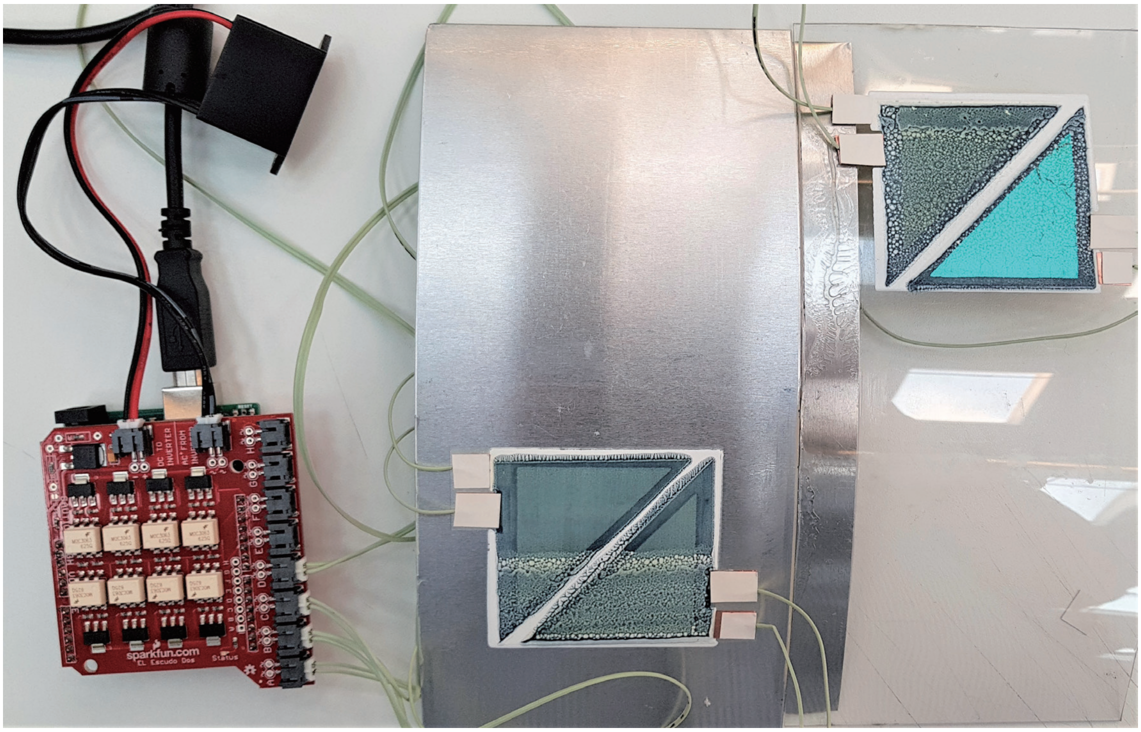



*Figure 48 - Electronic system connection*

## Conclusion

As a quick prototype, it is valuable with regard to suggesting how the concept can be fulfilled technically on the e-Palette car. The outcome is satisfactory when reflecting on the initial goal. My suggestion would be searching for alternative transparent conductive inks as top electrode for screen printing, which can be applied more uniformly. The other improvement is that the lamps can be fabricated with higher transparency varying on the inks slightly. This quality is unique when applying on glasses, creating see-through experience for both pedestrians and passengers.

# RECOMMENDATION

The recommendation is proposed to include these promising insights or ideas which have been abandoned for practical reasons and suggest how the concept can be further developed briefly.

**EL fabrication techniques**

The electroluminescence lamps can be made in two techniques in our faculty, namely screen printing and UV curable method. The former one has been used in the prototype fabrication for its seamless application. The UV curable method is a faster and more transparent option. It works by using two layers of ITO coated PET as the electrodes, which is transparent and very thin (25 micron). The dielectric layer is clear UV curable glue which can be hardened quickly when exposed to UV lamps. If Toyota plans to embed the EL on existing cars or use it as an extra component, this method will be more applicable, since it can be pre-made into stickers and attached on car panels directly.

**Design direction**

The design direction of vehicle to pedestrian communication is chosen mainly based on the current driving context. However, from the perspective of the EL material itself, one unique quality is its dynamic interaction with the environment such as water or pressure. This is an interesting aspect, possible to convey amazing experience to users.

**Concept details**

As discussed in the EL properties, the current lamps are not brightly visible in daytime, which may influence the practical application of the concept. The brightness can be expected to increase with the advance in layering materials. Currently available methods include increasing the powering voltage, using bright phosphor inks as well as enhancing the contrast with background colors.

It is acknowledged that no color study has been conducted so far to evaluate how different colors may influence user perception on the visual cues. According to the results of user test, blue is relatively “new” on cars and can indicate observers that the conveyed information is different than traditional signals. It is advisable to plan a detailed research to zoom into this topic.

Aesthetic aspect of the patterns can be improved further to create an extra selling point.

Further user tests can be targeted on diverse groups such as children and people with color blindness to make sure the cues are visible and comprehensible to all users. Real scenario simulation is suggested as well.

# REFLECTION

My personal goal of the graduation project is to create a meaningful design which should function in a way that the experience of the target users can be improved, either slightly or dramatically. When evaluating on the final concept, I am proud that most users agree that it can improve their crosswalking behaviours and create a more confident feeling. However, it is acknowledged that the concept still needs to be developed further in order to be applicable in a real scenario. For example, the aesthetic aspect has not been adequately considered yet, which is a pity considering the delicate patterns EL materials can present. Overall, the final concept is acceptable and effective as an early exploration of vehicle to pedestrian communication.

The challenge of this project lies in two aspects for me. Firstly, the electroluminescent material was a brandly new domain in the beginning and a lot of hands-on experiments are expected to learn about its properties. The material driven method is different than any of the projects I have worked on so far, therefore takes longer time to be familiar with. The other difficulty is about car design topic. I have almost no driving experience in my life which remains an obstacle to understanding the context. But in the process, I have succeeded to manipulate the design direction to more familiar ones, positioning myself as a pedestrian in the scenario. It helps significantly to involve myself better in the following ideation and concept development.

One improvement can be better planning of the project in detail. It has to be admitted that the project was poorly scheduled which has led to certain delays in the progress. For example, the analysis phase has gone through for too long, leaving limited time for the following design activities. In addition, arranging creative sessions and ordering materials etc. have taken longer time than I expected. It is advisable to consider these issues in advance.

Most of my hands-on experiments have taken place during the last several weeks for prototype building. It requires time and effort to practice on the fabrication. What I learn from this experience is that there is gap between theory and practice. Even though I knew sufficiently how the EL lamps can be built in theory, the actual demonstrator making has encountered a lot of unexpected problems, which might be simply caused by a tiny crack on the dielectric ink. This is a valuable experience, improving myself in terms of practical ability.

Overall, this project is quite challenging and I feel really fulfilled that I have succeeded in accomplishing it with a satisfactory design proposal.

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# APPENDIX A

## DRIVING EXPERIENCE USER INTERVIEW

### Participant 1 - Male

1. Have you driven a car before?
Yes.

2. In which situation will you choose to drive a car e.g.weather conditions, travel distance or group trip?
I used to have a car myself since I was 18, and i am 27 now. This is the first time that I do not have a car anymore. I used to go by car almost everywhere, back home to my parents. When I went to big cities like Amsterdam where parking is hard, I did not use it. Otherwise I would always.

3. What activities do you like to perform in the driving process?
I connect my phone so I can listen to music, using Spotify. I got to say sometimes I check my phone but I tried not to. And I always switch music that kind of stuff.

4. What do you enjoy most in your driving experience? How do you feel?
I enjoy the fact that I get some freedom from it. I really hate travelling by public transport, meaning that I need to be at station at certain time, which is super annoying. Because If I am 2 minutes late, I'm gonna miss the train. But if I am going by car, I am just 2 minutes late. Sometimes I can make up for it. Also I enjoy being alone there in my own space, where I can enjoy listening to music and don't bother other people. Also I am a car enthusiast, so I just like driving my cars.

5. What are the frustrating situations?
There's always negatives. I think in the Netherlands there's a lot of traffic, so in rush hours you always stand still. Also I cannot work travelling by car. When I am travelling in public transport, especially in 1 to 2 hours drives, I am working on my laptop a while. But when I am driving,I am just sitting there.

6. What's the difference between driving in daytime and at night?
I think night driving is more tiring. At night there's not so much traffic, so I am not triggered to pay attention. I am just sitting there when the driving is boring, thinking away in my mind.

7. Is there any inconvenience you've encountered in night driving, any examples?
Finding a parking space is really annoying, especially in large cities.

8. How would you evaluate your car's lighting considering the interior and exterior respectively? What problems do they have?
I will pick my last car. I think it's more than sufficient. In the inside, I think it's nice and clear enough because I had these LED lighting. So the normal yellow lighting is not sufficient.

9. What kind of lighting (features) do you want? Any requirements for night driving?
The problem I have for now especially for driving in the dark, is that you need to turn it off to look outside, to really see where it's driving and to make sure it's not tiring on the eyes. But you need to turn it on to see something. I would like to see some kind of solutions that I can just turn it on and don't get tired, such as ambient lighting.

10. How would you envision your ideal car in the next 5-10 years, or your most desirable driving features and experiences?
For me when I am buying a car I always want it to look aggressive. For the interior, I want it to be luxury and aggressive. Also I think the lighting in the old cars and new cars are progressed, more ambient lighting and looks more luxury.

## Participant 2 - Female

1. Have you driven a car before?
Yes, sometimes.

2. In which situation will you choose to drive a car e.g.weather conditions, travel distance or group trip?
It it's really bad weather, I would like to drive a car. Or if it takes quite a while to use public transportation, then I would prefer to take a car.

3. What activities do you like to perform in the driving process?
Listening to music would be one of the main things. I am not really into conservations when I am driving a car, otherwise you get distracted quite a lot.

4. What do you enjoy most in your driving experience? How do you feel?
You feel in control of the time it takes to get somewhere. Be independent of other people to get to somewhere.

5. What are the frustrating situations?
If I compare it with public transport, you can just read a book, do some work you still need to do. If you are driving car you really need to be focused and not do anything.

6. What's the difference between driving in daytime and at night?
Prefer daytime driving. Because at night it's so dark you need to be more aware of everything around you. It asks for more focus.

7. Is there any inconvenience you've encountered in night driving, any examples?
Other cars could have wrong settings for their lights, really annoying. When it's raining, it's horrible to drive, because the lights get even brighter. For me it starts to get dangerous.

8. How would you evaluate your car's lighting considering the interior and exterior respectively?

What problems do they have?
If you drop something on the floor and you switch on the light, it's almost never possible to find it, because it's not giving enough lights. It is bright enough but not enough, only two spots. For those cars with digital dashboards, it's distracting sometimes because they can be too bright.

9. What kind of lighting (features) do you want? Any requirements for night driving?
N/A.
I know some lights which you can set  to more red or blue lights depending on if it's day or night. It would be ideal if you could set the light intensity and colors, also separated lighting controls for drivers and passengers etc.

10. How would you envision your ideal car in the next 5-10 years, or your most desirable driving features and experiences?
I would not like to go into autonomous cars. Because I would like to be in control when I am in the driving seat. I would not being safe.

## Participant 3 - Male

1. Have you driven a car before?
Yes.

2. In which situation will you choose to drive a car e.g.weather conditions, travel distance or group trip?
Most of the time small distances like 10 to 15 minutes. Sometimes to families for like an hour.

3. What activities do you like to perform in the driving process?
Listening to music, talking and texting kind of stuff.

4. What do you enjoy most in your driving experience? How do you feel?
The feeling of freedom, like you can go anywhere and you are just sitting on the road for a long time on the highway.

5. What are the frustrating situations?
Traffic jams. Maybe if there are people in the back talking aloud, you cannot concentrate that well.

6. What's the difference between driving in daytime and at night?
I have to be more focused driving at night, because everything is more dark and you have to be really careful.

7. Is there any inconvenience you've encountered in night driving, any examples?
In the Netherlands, there are lights in the highway. Sometimes they turn it off, just to save energy and save money for the government. Sometimes it's annoying when someone is driving behind you and its lights shine in your mirror. And the lights reflect back in your eyes.

8. How would you evaluate your car's lighting considering the interior and exterior respectively? What problems do they have?
It does not have any problems. The car is BMW and it has orange lighting. I really like that color. It's good for your eyes. For the overhead light, I never turn it on when I am driving.

9. What kind of lighting (features) do you want? Any requirements for night driving?
I really like it blending in with the material, as part of the design.

10. How would you envision your ideal car in the next 5-10 years, or your most desirable driving features and experiences?
Fast, sporty, good looking.
Interactive lights that adapts to the environment. Maybe it can select the best lighting for you, different lighting mode in various contexts.

## Participant 4 - Male

1. Have you driven a car before?
Yes.

2. In which situation will you choose to drive a car e.g.weather conditions, travel distance or group trip?
Usually I use them to drive within city.

3. What activities do you like to perform in the driving process?
Listen to music.

4. What do you enjoy most in your driving experience? How do you feel?
I don't drive that much. So I enjoy the fact that I am using a car instead of riding a bike etc.

5. What are the frustrating situations?
I like to drive in the evening, because there are not a lot of people, so I don't need to check the road constantly. When I drive in the morning, there are a lot of people in the city and children from school. I have a lot to consider then.

6. What's the difference between driving in daytime and at night?
I feel more calm in night driving. I can focus more on the road. During daylight, there are too many distractions.

7. Is there any inconvenience you've encountered in night driving, any examples?
N/A.

8. How would you evaluate your car's lighting considering the interior and exterior respectively? What problems do they have?
Nothing special. Normally when I am using the overhead lighting, I am searching for something.

I don’t use it when I am driving. My current ceiling lighting is too much to check phones and turn on the radios etc.

9. What kind of lighting (features) do you want? Any requirements for night driving?
A smart light which I can use to turn on the radio and check my phone, that's fine.

10. How would you envision your ideal car in the next 5-10 years, or your most desirable driving features and experiences?
Automatic features, such as the window. Luxury cars, you can do a lot of stuff inside a car. You have more options.

## Participant 5 - Male
1. Have you driven a car before?
Yes.

2. In which situation will you choose to drive a car e.g.weather conditions, travel distance or group trip?
If there’s an emergency or if I want to be somewhere fast, I would go for a car.  And if I am going a long trip or picnic, I would choose a car as well.

3. What activities do you like to perform in the driving process?
Listen to music, talk to someone besides me.

4. What do you enjoy most in your driving experience? How do you feel?
I enjoy the feeling of controlling the car. It’s really nice, such as the window opener, console buttons etc. You feel like controlling something nice.

5. What are the frustrating situations?
Too many people talking on the car, and at the sametime you really need to focus on the driving.

6. What’s the difference between driving in daytime and at night?
Night driving has to be more cautious and alert than daytime driving.

7. Is there any inconvenience you’ve encountered in night driving, any examples?
The lights on navigation boards, panels and ceiling lights could give me distraction sometimes, with its red or blue colors.

8. How would you evaluate your car’s lighting considering the interior and exterior respectively? What problems do they have?
N/A.

9. What kind of lighting (features) do you want? Any requirements for night driving?
There are low intensity lights which are enough to keep you aware of the environment. It’s not so

bright that everyone can see what’s happening inside your car, but it’s for you who is driving. It's evenly distributed everywhere, causing no distraction.

10. How would you envision your ideal car in the next 5-10 years, or your most desirable driving features and experiences?
Self-driving cars. Smart ones which can understand contexts, interact with me and understand what I might need.

# APPENDIX B

## CREATIVE FACILITATION

### PLANNING

**Problem definition (25 min.)**
Story telling - each participant tells his/her crosswalking strategies and frustrating situations (5 min.)

Drawing your problem - ask the group to produce a drawing or sketching depicting the problem figuratively, in this way understanding of the problem is shared among group members(10 min.)

H2 - generate "how to..." questions (5 min.) and choose a most promising one as the new problem statement (10 min.)

**Idea generation (90 min.)**
Shedding the known - write down the solutions and ideas that are already in the participant's mind (20 min.), and say it out
Break (5 min.)

Matec - choose a key term (or 2) in the problem statement and form a 5*5 matrix. Then two words that are far from the problem statement are chosen and the participants are asked to formulate what these have in common. The found common quality is taken as the starting point for ideation. (25 min.)

Random picture - show team members random pictures and ask them to use it as starting point for ideation based to their own interpretation (20 min.)

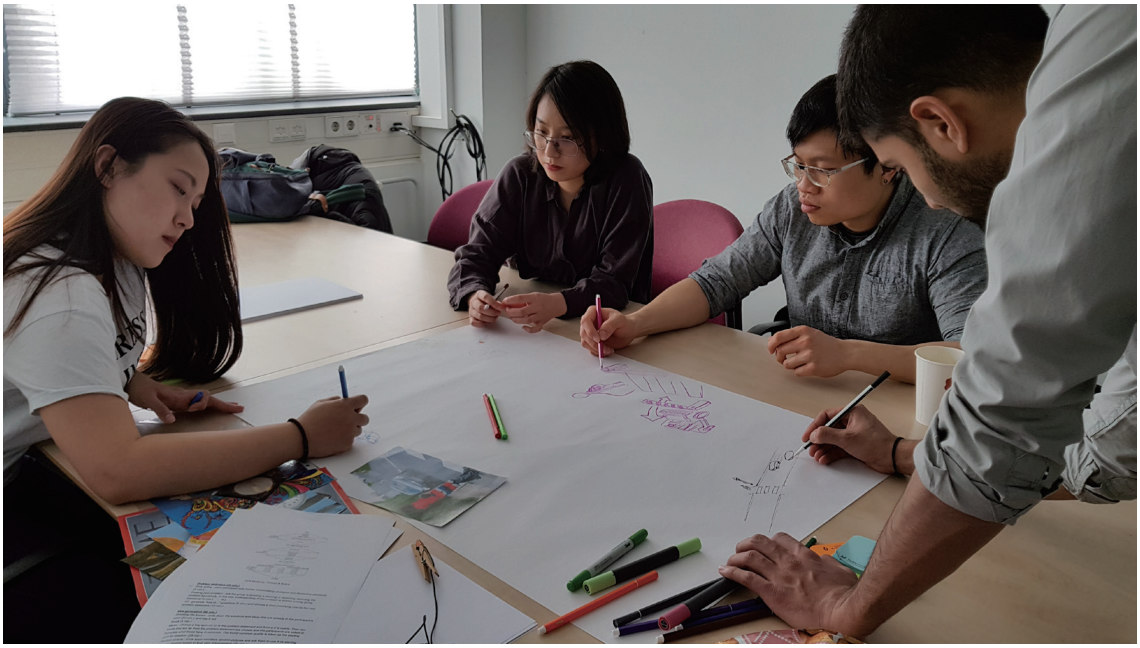
Grouping - group these generated ideas into different categories and give a name for each group (10 min.)

Dots - every team member can have three dots for their supporting ideas, discuss about their selections and choose a final idea (10 min.)

**Concept development (20 min.)**
Magazine cover - improve the concept and present it as a magazine cover, which shall include title, slogan, picture and quotes etc.

## PROCESS

The problem definition phase starts with every participant telling their crosswalk strategy and encountered frustrating situations. It is an easy way to get team members quickly involved in the context. It is followed by problem drawing process, creating a sketching by team members together depicting the problem visually according to their interpretation. In this way, the problem and broader context is explored and communicated. The last part of this phase is called “how to”, during which participants have been required to propose questions starting with “how to” based on the given problem, since it is a natural expression to stimulate solution finding unconsciously. In the end, we have chosen the main design target as “how to facilitate the communication between vehicle and pedestrian in crosswalk scenario?”



The ideation phase is the key part of the CF session. It is always beneficial to start with shedding the known, to write down the ideas already in mind and make room for more innovative and crazy solutions. After this, two techniques have been applied to stimulate the team members for idea generation. Random picture tends to be more useful in the process. It works by showing team members several pictures one by one and using them as stimulator for idea proposal. The strength of this method lies in that participants can interpret these images quite differently, focusing on the whole structure or detailed features to make association. When the ideas have been collected, a clustering process has been performed, by classifying them into different categories. By means of grouping, an overview and organization of the generated ideas have been made. The last part of this phase is to choose one idea for the concept improvement. Idea “speed indicator” has been selected as the favorite option by group voting and discussion.

*Figure 51 - Idea clustering*


*Figure 50 - Images for ideation*

In the concept improvement phase, the team members need to detail the selected idea and present it in the form of a magazine cover which should include slogan, drawing, quotes etc. The core value of this process is to specify the meanings participants have identified for the concept.


Figure 52 - Example magazine cover

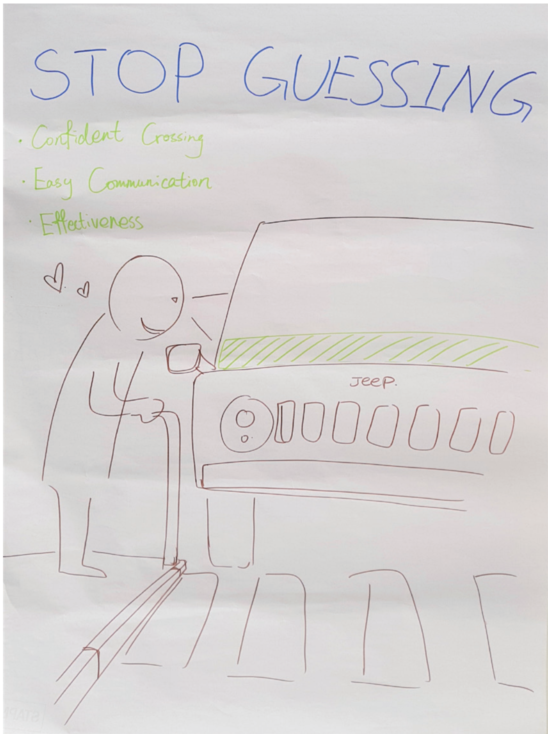


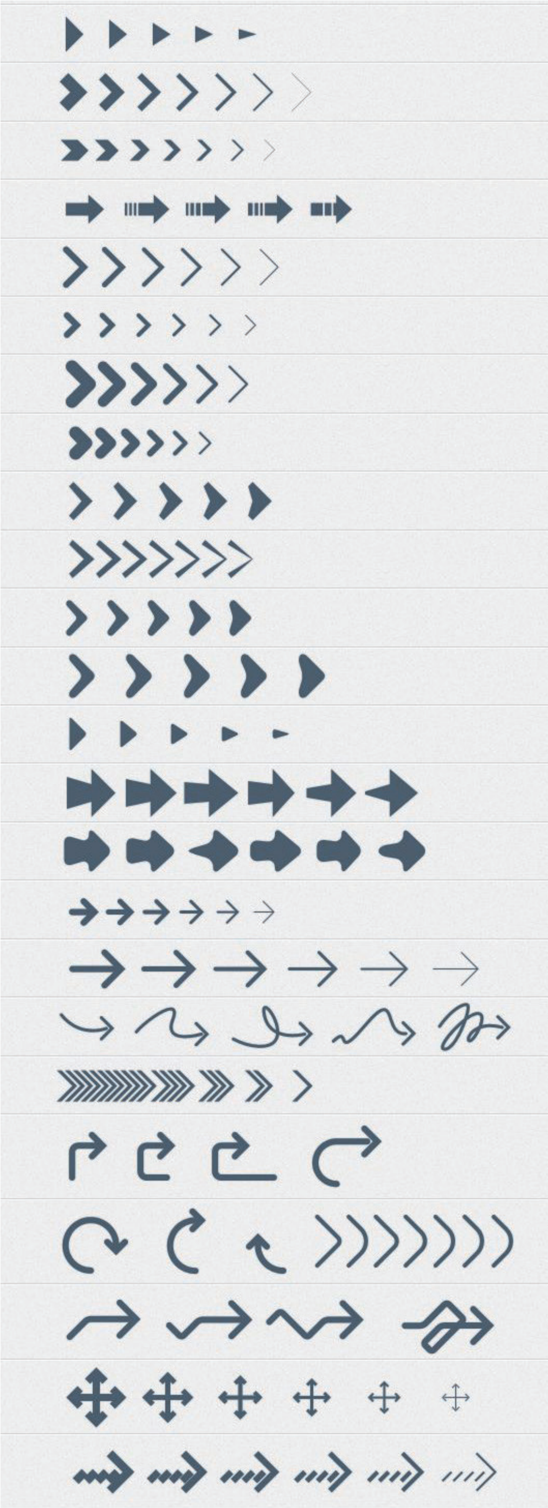

Figure 53 - Selected idea “speed indicator”

# APPENDIX C

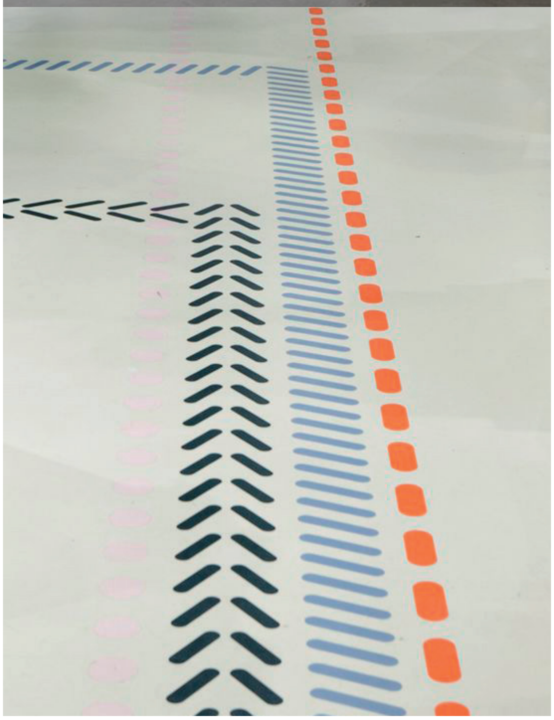
## CONCEPT INSPIRATION

### AUTO driving


### Pattern inspirations




HALL 8
8
FRACTURE GALLERY



# APPENDIX D

## USER TEST REPLIES

### Participant 1

1. In general, how clear the communicated information of the design is to you? Which visual cues are confusing? (Ranking from 1 to 5 ---- 1 means not at all, 5 means definitely)
I would give 4.
Auto driving mode is unclear, similar with wifi or internet connection. Pedestrian detection can be confusing with turning signals.

2. In the listed stages of auto driving context, when will you start to cross the street? Why?
When the car almost stops and I am sure I will be safe. For now, I am not so confident in autonomous cars, therefore would like to wait till there is no risk.

3. What about in human driving mode? Will that make any difference to your crosswalk decisions?
I will cross directly when the car starts to decelerate, because I believe in human driving skills.

4. How do you think this design will influence your crossing behaviours? In which way?
In the current crosswalk situations, I need to communicate with drivers for further reaction. This interaction is emotional and subjective, causing misunderstanding sometimes. The concept can help to decrease the confusion and confirm whether I can cross or not. The other benefit is I can be free from social pressure. No eye contact or feedback need to be given to drivers.

### Participant 2

1. In general, how clear the communicated information of the design is to you? Which visual cues are confusing? (Ranking from 1 to 5 ---- 1 means not at all, 5 means definitely)
I will give 3. The deceleration and acceleration cues are nice, giving me feelings that the car is breathing in and out, human-like expressions. And the color blue is something new which has not used on cars so far. It can link me to new meanings of the light.

The confusing part is the pedestrian detection. It is more like a turning signal for me, partly because of its shape. It can be designed in a more round or eye like patterns.

2. In the listed stages of auto driving context, when will you start to cross the street? Why?
In the first several times, I will cross when the car completely stops with the inward arrow signs. After that, when I am familiar with the system, I will cross when it almost stops.

3. What about in human driving mode? Will that make any difference to your crosswalk decisions?
In human driving mode, I always look for eye contact with the driver to tell him you'd better stop… At night I tend to be more careful. I will probably cross when the car is in the process of deceleration. But the actual speed and movement can be influencing as well.

4. How do you think this design will influence your crossing behaviours? In which way?
It gives me extra confirmation that the car is slowing down gradually, making me feel more secure in crosswalking situations. For autonomous cars, communication with pedestrians is a really important aspect. The technology is developing quickly but people don't know the system and how it works. It is a new way to talk with pedestrians without using texts.

### Participant 3

1. In general, how clear the communicated information of the design is to you? Which visual cues are confusing? (Ranking from 1 to 5 ---- 1 means not at all, 5 means definitely)
4.
The auto driving means wifi and driving wheel. It makes sense to relate it with auto driving mode. And the pedestrian detection is clear if you know the use cues. For the deceleration and acceleration, the down & up tendency and visual form is clear and interesting. It is quite logical to understand.

2. In the listed stages of auto driving context, when will you start to cross the street? Why?
When the car starts to decelerate.

3. What about in human driving mode? Will that make any difference to your crosswalk decisions?
Almost makes no difference. I will go when the car is in the process of slowing down.

4. How do you think this design will influence your crossing behaviours? In which way?
In the current situation, the person needs to calculate whether he can go or not. The driver and pedestrian is guessing each other's intentions. It can cause confusion. But with the design, there will be no extra thinking needed. I won't be that scared when crosswalking.

### Participant 4

1. In general, how clear the communicated information of the design is to you? Which visual cues are confusing? (Ranking from 1 to 5 ---- 1 means not at all, 5 means definitely)
3.
The pedestrian detection can be confusing. It requires extra learning of its meaning. For me, it can mean something else, such as the car is turning directions. For the other parts like deceleration and acceleration, I think they are quite logic and easy to understand.

2. In the listed stages of auto driving context, when will you start to cross the street? Why?
When the car almost stops and I am sure I will be safe.

3. What about in human driving mode? Will that make any difference to your crosswalk decisions?
I probably will cross a little bit earlier, because I know the driver won't hit me.

4. How do you think this design will influence your crossing behaviours? In which way?

It can bring a lot of safety actually. Pedestrians can cross the street with more certainty and security. If the system is everywhere, there will be less accidents happening. It avoids the confusing situations that the driver doesn't see the pedestrian or has no intention to slow down etc.

**Participant 5**

1. In general, how clear the communicated information of the design is to you? Which visual cues are confusing? (Ranking from 1 to 5 ---- 1 means not at all, 5 means definitely)
5 actually.
The auto driving signal does not really feel like steering wheels.

2. In the listed stages of auto driving context, when will you start to cross the street? Why?
I will cross when the car stops completely. Because it's a machine, I would like to know as much information as possible. Only when it stops, I can be sure it sees me.

3. What about in human driving mode? Will that make any difference to your crosswalk decisions?
Yes, it can make a lot of difference. Human drivers have empathy about pedestrian crossing so the communication is human like.

4. How do you think this design will influence your crossing behaviours? In which way?
It can bring me more trust on these autonomous cars. Imagine that in the future cities everything is autonomous. There will be no humans involved. The design can provide some kind of relations or information exchange between pedestrians and the machines. That can help to build trust. The other benefit is I feel more safe walking in the city because I can be aware of the cars movements.

# APPENDIX E

## SCREEN PRINTING DIELECTRICS

In the process of EL screen printing, several dielectric materials have been tested so far, including Dupont dielectric 7165, barium titanate and Aquaplast - DIY transparent binder as shown in the following figures, with barium titanate as the final option.

Comparing these three dielectric materials, both Dupont and Aquaplast are transparent when applying on the rear electrode layers, therefore, tend to be a better option than the white barium titanate in the beginning. Dupont is quite thick, which can be easily applied evenly with excellent dielectric performance. It is also the reason why Dupont is perfect as the isolation layer. However, the biggest problem when using it as dielectric is that the PEDOT:PSS which is supposed to be applied on top of it cannot attach well, with significant cracks and patterns on it (see fig. 55). In terms of the Aquaplast, it is actually the best base material for PEDOT:PSS among these options. But it is really weak in terms of dielectric qualities, partly due to its juicy textures. Some short circuit sparks have been observed. Barium titanate is just an acceptable option, with reasonable qualities in terms of dielectric performance and PEDOT attachment.

In the test, I have tried to apply layers of Dupont and Aquaplast on top of each other as the dielectric, expecting to combine their advantage. It works, only that the brightness of the lamps have been sacrificed so much. This scheme has been abandoned therefore.


*Figure 54 - Dupont and aquaplast*

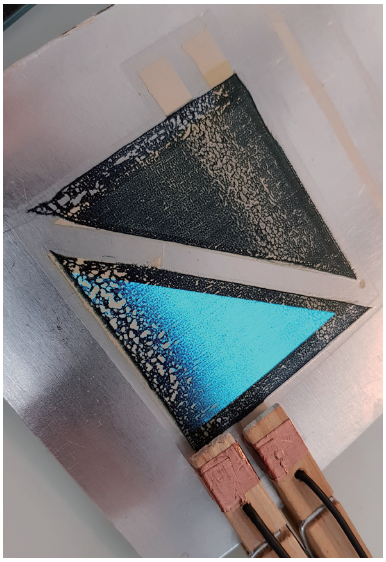


*Figure 55 - Dupont dielectric lamp*

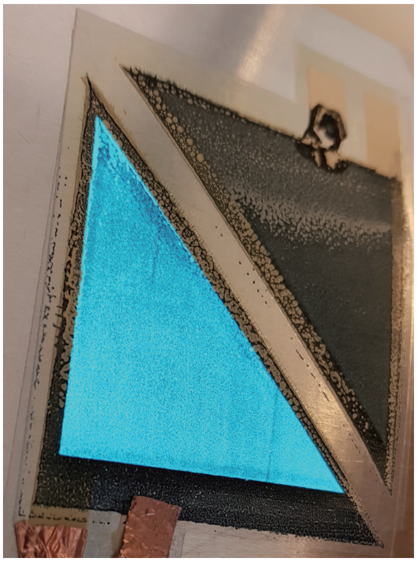


*Figure 56 - Aquaplast dielectric lamp*