Projection car glass: A way to enhance the in-car experience by using different projections on the car roof

Xinyue Liu
Eindhoven University of Technology
Eindhoven, the Netherlands
x.liu2@student.tue.nl

ABSTRACT

This research aims to explore how roof light design can enhance the in-car experience. It examines current trends in vehicle lighting design, and through design and technical analysis of different vehicle lighting designs, it uses a combination of projection and PDLC glass to provide diverse projection effects for different scenarios. By replacing the original lighting with projection, it achieves personalisation and atmosphere creation, providing users with a completely new experience that is different from fixed lighting effects.

KEYWORDS

Vehicle lighting design, user experience design, projection

1 Introduction

With the increasing diversity of consumers' lifestyles and travel needs, the use cases for vehicles have expanded significantly, giving rise to the concept of mobility as a service [1]. Beyond daily commuting and long-distance travel, activities such as camping overnight, working inside the vehicle, and gaming and entertainment have all become part of the application scenarios for electric vehicles. As a result, when consumers purchase vehicles nowadays, in addition to vehicle performance and price, the driving experience has increasingly become a key consideration, driving design trends toward a higher level of in-vehicle experience. This is also why manufacturers are gradually shifting from a mechanically-centric approach to a user-experience-centric one [2].

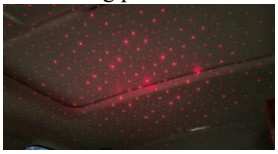
In particular, vehicle lighting design has become an important part of this trend. Beyond basic lighting functions and aesthetic decoration, creating ambiance and interacting with people have emerged as new trends, offering greater safety and personalised experiences [3]. Additionally, panoramic sunroofs are increasingly becoming standard features in mid-to-high-end electric vehicles [4]. Combining these two elements, roof lighting design presents a potential way to improve the in-vehicle user experience.

Therefore, this research aims to explore how advanced lighting solutions in panoramic roofs can improve in-vehicle driving experience. The research focuses on L3-level vehicles in the coming 7-10 years. Through design and technical analysis of different vehicle lighting solutions, it adopts a combination of projection and PDLC glass to provide diverse projection solutions for different scenarios. By replacing traditional lighting with projection technology, it achieves personalisation and atmosphere creation, offering users a completely new experience that is distinct from fixed lighting solutions.

2 Related Works

2.1 Roof light technology

Table 1. Roof Light Technology

Name and technology	Example with picture
1) Multi-fibre combined luminescence Multiple LEDs + multiple optical fibres combined to guide light	Rolls-Royce starlight headlining 
2) Backlit laser engraved Backlit + Laser engraved roof glass	BMW i7 
3) Translucent leather light guide Translucent leather wrap + Light guide plate design	Fangxin's tech demonstration in 2024 Beijing Auto Show 
4) Projection Laser projection to the roof	Retrofitting products 

Roof lighting has evolved from traditional lighting technology to a more functional role, serving as a means to improve the user experience and an essential part of the in-car interactive system. It commonly employs LED matrices and optical fibres [5], thereby enhancing the user experience. Currently, there are four technical concepts for roof lighting. The first involves fixed patterns created using countless tiny LED lights and guiding fibres. Due to its high cost and the need for manual production, this technology is commonly found in luxury vehicles, such as Rolls-Royce's starlight roof [6]. The second involves laser-engraved patterns on the inner layer of glass, with lighting effects created by side lights, such as the roof glass lighting in the BMW i7 [7]. This is also the most widely adopted roof lighting technology. The third involves using semi-transparent leather and light guides to create lighting effects [8], with samples already exhibited at auto shows. The fourth uses a simple projection device to project onto the roof, typically purchased by users themselves, producing a basic light spot effect [9].

2.2 Car sunroof glass

When it comes to sunroofs that incorporate roof lighting, most currently use smart dimming glass, which offers basic functions such as automatic dimming, temperature regulation, UV protection, and automatic shading. An example is the sunroof glass in the BMW iX [10]. Of course, a small number of systems use customised films placed between the glass layers to further adjust the glass colour [11]. However, the three most common types are PDLC colour-changing glass, thermochromic glass, and EC glass. PDLC glass involves adding a PDLC film between two glass panels. By applying a voltage to the terminal, the particles in the PDLC film align in a specific direction, thereby altering the glass's light transmittance [12], as shown in the Figure 1.

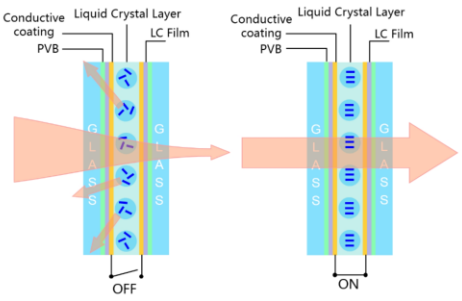


Figure 1. PDLC glass principle

This type of glass is inexpensive and widely used, typically exhibiting a milky white visual effect. Thermochromic glass alters the arrangement of particles through temperature changes, absorbing heat to transform into coloured particles and thus becoming opaque [12]. EC glass imparts a sunglasses-like effect to glass by utilising the optical properties of materials (typically tungsten trioxide) to undergo stable and reversible redox reactions, thereby altering the glass's light transmittance [13]. Additionally, SPD glass is subject to restrictions due to safety risks associated with its higher operating voltage. Detailed technical survey is provided in the Appendix A.

2.3 Projection technology

Projection technology is widely used in automotive design, with common technologies including DLP, LCD, and laser projection systems [14]. DLP uses a micro-mirror array to reflect light, opening and closing as needed to project images. LCD uses light modulated by a liquid crystal panel to project images. Laser projection uses a laser as the light source to project images. In addition, head-up displays can also be considered a type of projection technology.

3 Methodology

This study adopts the 'Double Diamond Model' (see Figure 2) as the core methodology for design research [15], systematically advancing through four stages: 'identifying the problem,' 'defining the problem,' 'developing the design,' and 'drawing conclusions.' This model emphasizes divergent thinking in the design process, followed by convergent organisation to drive the formation of solutions.

During the problem identification stage, the research team conducted extensive literature reviews and desk research to collect and organise existing data on vehicle lighting design, covering its various forms and development trends in terms of functionality, safety, aesthetics, and interactivity.

In the problem definition stage, the research further focused on the user experience dimension, constructing typical user journeys and conducting in-depth analyses and refined categorisations of the issues based on actual usage scenarios. This process helped clarify key user pain points and design intervention entry points, laying the foundation for subsequent design concept proposals.

During the design development phase, multiple rounds of brainstorming were conducted to generate preliminary concept proposals through divergent thinking, which were then screened and integrated based on feasibility, innovation, and user needs. Subsequently, representative design directions were selected for preliminary prototype creation and iterative improvements.

Finally, in the conclusion phase, the study summarised the effectiveness and shortcomings of the design based on test data and user feedback, while reflecting on the challenges faced and strategies employed throughout the design process.

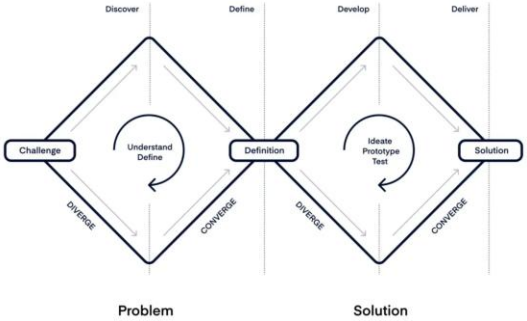


Figure 2. Double Diamond model

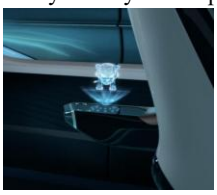
4 Design Research Process

4.1 Survey

4.1.1 Survey process. Conduct research on current vehicle lighting trends, refer to previous research methods [16], classify according to different functions, and select 1-2 typical cases for each function. As the survey focused on near-future lighting trends, both production vehicles and concept vehicles were included. The results are shown in Table 2 below.

Table 2. Roof Light Technology

Function	Example with picture
Dynamic lights (Outside lights)	Audi 
Dynamic lights of customised pattern (Outside lights)	AITO M9 
Dynamic lights of color for communication (Outside lights)	Chrysler portal concept 
Autopilot indicator lights (Outside lights)	Roewe Vision-i Concept 
Outside display for entertainment (Outside display)	MINI Vision Next 100 Concept 
Dynamic display of words and pattern for communication (Outside display)	Hyundai Mobis Concept 
Outside screen (Outside display)	Toyota Fun Vii Concept Car 
Projection of distance (width, length) (Projection)	AITO M9 
Active avoidance of in-front vehicles (Projection)	Audi 
Dynamic projection for entertainment (Projection)	Audi 
Dynamic projection of films (Projection)	AITO M9 
Dynamic projection for communication (Projection)	MINI Vision Next 100 Concept 
Interactable dynamic projection (Projection)	MINI Vision Next 100 Concept 
Real-time customised projection (Projection)	Deepal S05 
Use color and words to interact with driver (Interactable lights)	MINI Vision Next 100 Concept 
Lights for interaction in smart surfaces	BUICK GL8

(Interactable lights)	
Around lights with dynamic effect and customised color (Ambient lights)	Mercedes-Benz S Class 
Wrap-around display (Ambient lights)	DFM eπ 2024 Concept Car 
Interior projection on floor (Interior projection)	Roewe Vision-i Concept 
Interior projection on windows (Interior projection)	Roewe Vision-i Concept 
3D projection of mascots (Interior projection)	Geely Galaxy Starship Concept 
AR display (AR)	Audi activesphere concept car 

4.1.2 Survey result.

From the research, it can be seen that current vehicle lighting design has functional differences due to the disparities between interior and exterior design. For exterior design, the trends can be summarised as dynamic lighting effects, customisable patterns, and improved interaction with people. For interior design, the trends can be summarised as ambient lighting, entertainment-focused features, and similarly improved interaction with people. Additionally, the integration of projection technology has made interaction with people easier and enabled vehicles to project movies and other content.

In summary, the overall trends in vehicle lighting are: easier information exchange with people inside and outside the vehicle, more practical interaction, real-time and customisable features, and dynamic changes based on factors such as temperature and mood. Therefore, how to incorporate these trends into the lighting of the vehicle's sunroof has become the next area of research.

4.2 Further analysis

Whether this is good represents a good user experience is a question that needs further exploration. Therefore, we listed the user journey for possible scenarios involving sunroofs for

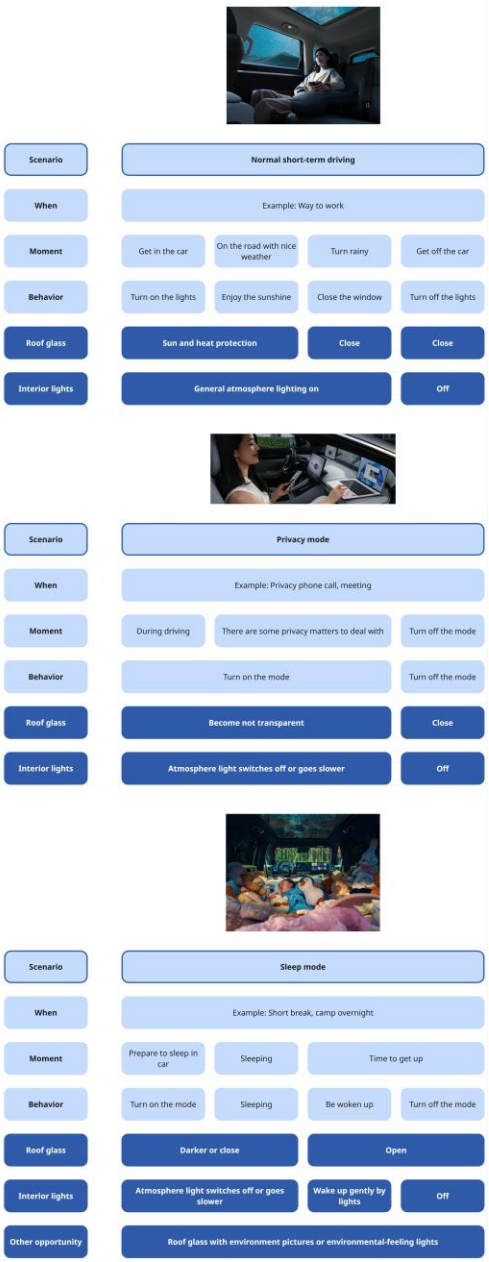


Figure 3. User journey

discussion, as shown in Figure 3. The user experience map is based on empathy, experience, imagination, and establishment from a first-person perspective.

It can be observed that in ordinary short-distance travel scenarios, there is a need for heat and sun protection for the roof lights, and an automatic on/off function for the interior ambient lights. In work mode and other private modes, the car windows need to darken, so the roof sunroof no longer needs to be transparent, and the interior ambient lights require an automatic on/off function based on the mode. For sleep mode, the roof sunroof requires darkening or closing, and interior ambient lighting requires automatic on/off functionality, or alternatively, the roof glass can display environmental photos or ambient lighting. For gaming or music mode, the roof sunroof requires darkening or closing, and interior ambient lighting requires changes in rhythm or atmosphere, or alternatively, the roof glass can display gaming or movie content. The details are summarised in Table 3 below.

Table 3. Function requirements

Function	Scenario amount
Sun and heat protection	1
General atmosphere lighting on	1
Darker or close	3
Atmosphere light switches off or goes slower	2
Atmospheric lighting in line with the game and music rhythm	1
Roof glass with environment pictures or environmental-feeling lights	1
Show games or videos like movies on the roof glass	1

In summary, the smart tinted glass on the roof of the vehicle itself can achieve all of the above functions. The remaining requirements focus on how to display environmental photos, ambient light, games, or movie content on the roof glass.

4.3 Iteration 1

4.3.1 Design.

There are many possibilities for this requirement, but none of them can be achieved with existing sunroof lighting. An analysis of the sunroof lighting technology section in related works reveals that current sunroof lighting has several issues: most designs are based on starry skies, they can only change colour but not shape, and few can be customised. Therefore, to meet the requirement, a new approach is needed. One concept involves using transparent TVs for display, which could easily meet the demand for personalisation and diversity. However, the strength of transparent TVs is not as high as that of car window glass, so they cannot be considered for safety reasons. Therefore, a more suitable approach is to use projection onto the roof glass, as shown in Figure 4.

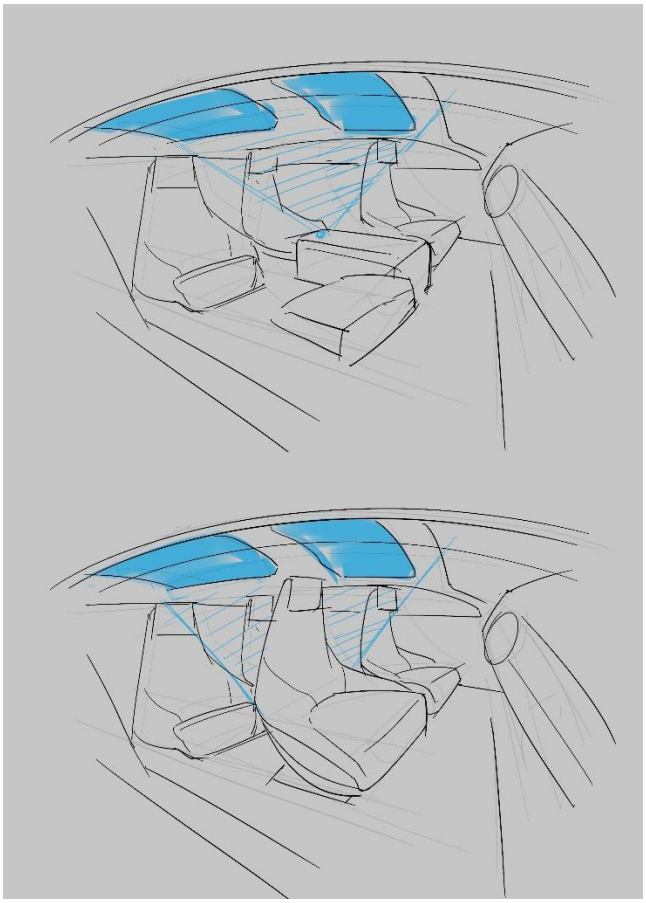


Figure 4. Iteration 1 drafts

4.3.2 Little test.

To achieve this concept, two conditions must be met. First, the projector selected must not be of a high-intensity type that could harm the eyes, nor should it be of such low intensity that it cannot project properly. Second, the roof glass must be able to function as a screen.

From the skylight technology section of related works, it can be concluded that currently common smart tinting glass has three colours when non-transparent, namely off-white (PDLC glass), off-black (high-quality EC glass or closed skylight sunshade), and off-blue (low-quality EC glass). Three coloured papers and light sources were selected for testing, as shown in Figure 5.

Figure 5. Light backing test

It is evident that under conditions of indirect sunlight, the projection centre intensity exhibits a pattern of white background > blue background > black background. Considering the relatively low cost of PDLC glass, PDLC glass that turns milky white when the power is turned off is selected as the projection screen.

4.3.3 Evaluation: Workshop.

Regarding the selection of projection content, a workshop format was used to gather ideas and conduct evaluations.

Five young people in their mid-twenties participated in the workshop. The workshop involved in-depth discussions on three scenarios: commuting to school, day trips, and long-distance travel. Participants imagined the possibilities of rooftop projection lights suitable for resting, entertainment, and sleeping in different scenarios, as shown in Table 4. Specific details and translations are provided in Appendix 2.

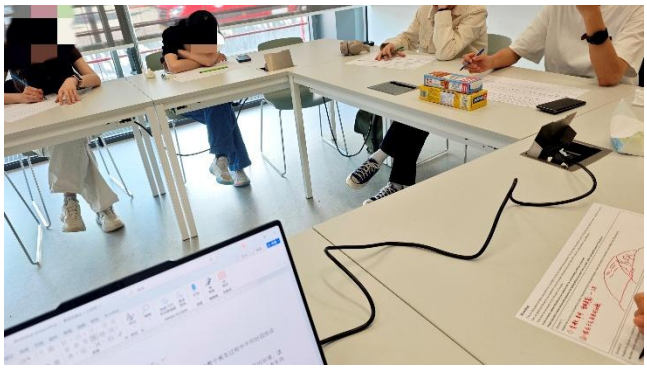


Figure 6. Workshop photo 1

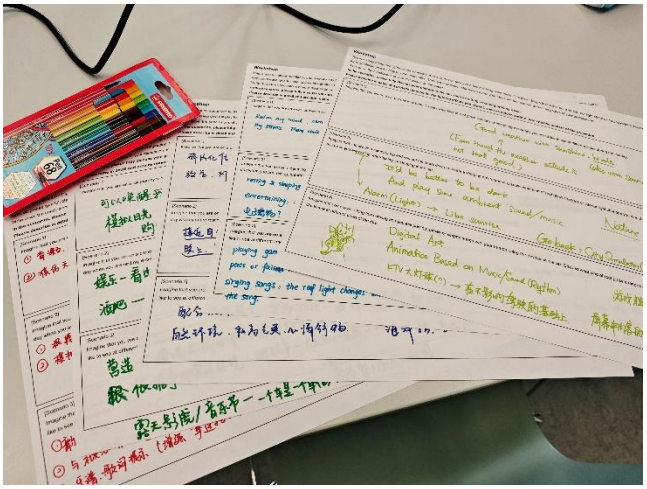


Figure 7. Workshop photo 2

Table 4. Workshop result

Kind	Detail
Simulate weather	a. Give people the feeling of sunny days even on rainy days b. Real-time weather c. Cold light in summer and warm light in winter
Practical information display	a. Weather forecast b. News, shopping information, city tour c. Location display of external people or objects d. Chatbox while lying down e. Texts and words of studying
Simulate natural environment	a. The breeze in the woods b. In the water with fish swimming c. The real starry sky
Simulate artificial environment	a. Simulate in the bedroom (Like ceiling) b. Simulate stage atmosphere c. Simulate bar atmosphere d. Simulate toys for babies
Respond to the music	a. Rhythm lights of the music b. Simulate KTV, display MV, lyrics, etc.
Respond to games and movies	a. Atmospheres of the games or movies (Like dark, cheerful) b. Atmospheres of victory and defeat (Like colorful streamers)
Digital pet	/
Helping to wake up	/

In summary, it can be broadly divided into three parts. The first is the display of specific information, such as weather forecasts, surrounding information, chat boxes, etc. The second is the rendering of the interior atmosphere, such as responding to the external environment, counteracting the external environment, and constructing a fantastical environment. The third is responding to

other matters, such as responding to music rhythms and responding to the atmosphere of games or films.

4.4 Iteration 2

4.4.1 Design and generated videos.

As shown in Figure 8, the projected video image is constructed based on the results of iteration one.

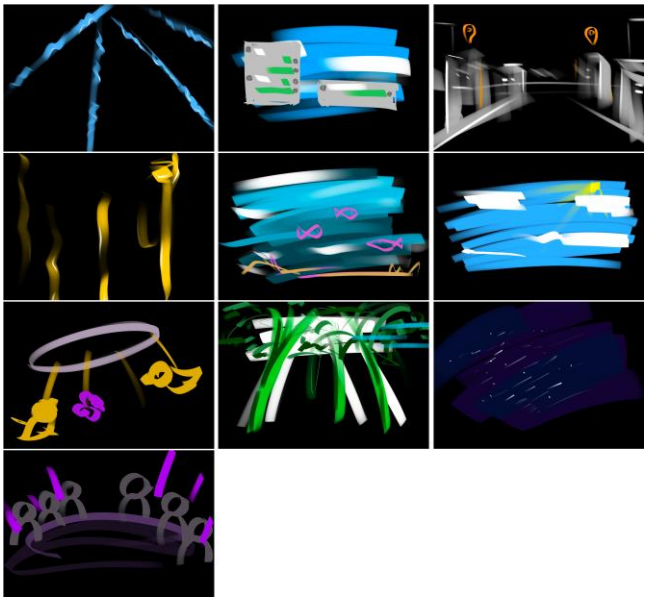


Figure 8. Iteration 2 drafts

The thing is, because the projection wasn't super accurate and there were a bunch of screens in the car, some info stuff got left out, like dialogue boxes. To make the design more flexible, apart from custom videos people upload, the rest of the videos should be automatically generated by AI and shown or not based on the situation. The final videos are shown in Figure 9, and the AI prompts are in Appendix C.

The videos are as follows: (1) A sunny sky with blue skies and white clouds displayed in rainy weather to lift spirits. (2) A realistic starry sky when spending the night inside the car at night. (3) A gentle breeze rustling through the trees during outdoor camping. (4) An immersive experience resembling an aquarium deep underwater. (5) A bar atmosphere with wine bottles and dim lighting. (6) A bedroom ceiling-like ambiance when spending the night inside the car at night.

4.4.2 Evaluation: Test.

Test Purpose: To test whether the lighting effects of the projection lamp can enhance the atmosphere. Test Materials: A PDLC glass sample measuring 1120 x 800 mm, a simple projection device, and 6 test videos. Test Participants: 11 young adults aged 20–28.

Test Process: Have the test participants sit in chairs facing the projected glass panel and imagine themselves inside a vehicle looking through the sunroof. Six videos will be played, each corresponding to a different scenario. Test participants are required to answer whether the projection enhances the experience of the scenario or share any other thoughts. After completion, they will fill out a UED evaluation questionnaire which is in Appendix D.

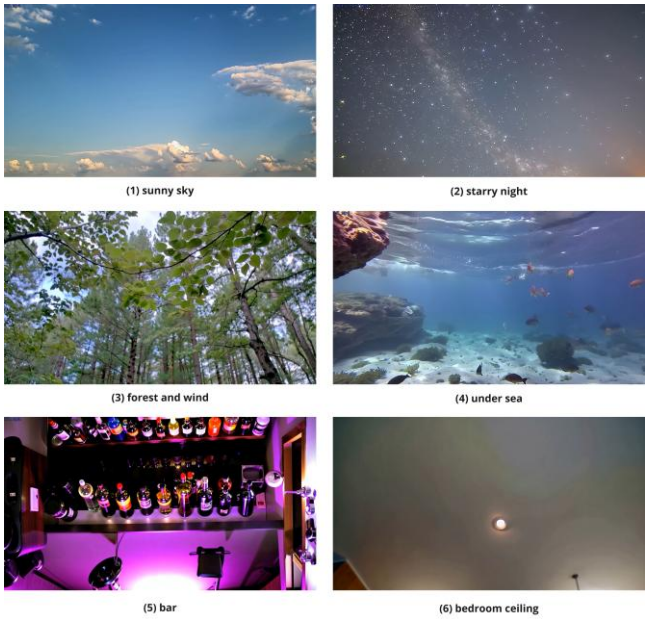


Figure 9. Iteration 2 generated videos

Figure 10. Test process

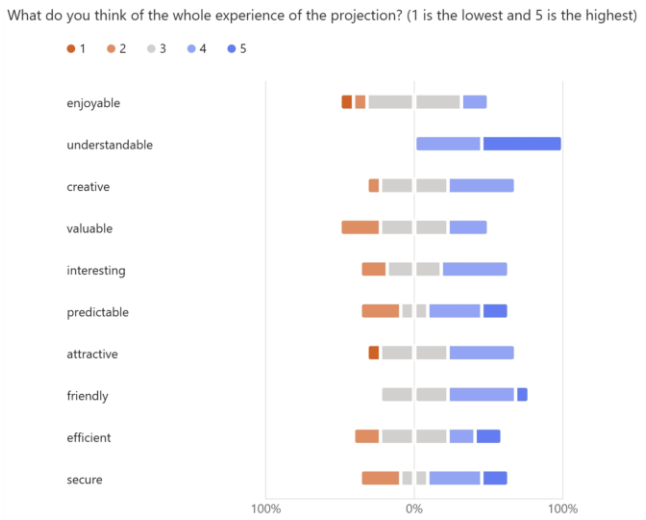


Figure 11. Test questionnaire result

According to the results of the test questionnaire, as shown in Figure 11, it can be seen that understandable received the highest score, meaning that the video conveys information or atmosphere with minimal misunderstanding. Additionally, friendly, predictable, and secure also received high scores, indicating that the video itself does not pose a safety hazard to drivers by being overly abrupt. Attractive and interesting also scored reasonably well, suggesting that the video effectively enhances user experience, though further testing is needed. Valuable received the lowest score, as many testers did not perceive adding lights or projections to the window as meaningful to them, and they did not recognise the value of the atmosphere. This may also suggest that such design approaches are likely to be confined to high-value-added services.

Table 5. Test result 1

Video	Positive	Amount	Negative	Amount
Sunny sky	Focusing on projection will have an effect.	1	You can still see the rainy weather outside, so there's no point in hoping for sunny weather.	1
			I don't like being too different from others.	1
			I personally enjoy rainy days.	1
Starry night	The direct starry sky is better.	2	It's too dark to see clearly.	2
	I prefer a dimly lit environment when resting.	1	I don't like effects that are too bright.	2
Forest and wind	You will love the feeling of the breeze in the forest.	5	In the park, you can open the skylight directly without further projection.	1
			It feels very scary to be in a car surrounded by trees.	1
Under the sea	The underwater scenes are very interesting.	5	Feeling scared underwater	1
			Too detached from reality, unsuitable	2
Bar	Blue-purple, laser-like lighting	1	The actual wine bottle effect is not suitable.	6
	The projection of a futuristic person	1	Depends on the vibe of the party	1
Bedroom ceiling	You can cast crystal chandeliers.	1	Computer wallpaper animation	1
			There is no need to project onto the bedroom ceiling.	5
Others	Directly play music videos and movies	2	Not a required item	1

Dance to the rhythm of the music	3	Not suitable for driving	1
preference for small animals	3	Very strange.	1
Bubbles, bouncing balls	1		
It's quite interesting to cheer for the winner when they win the game.	1		
Reduce motion sickness	1		

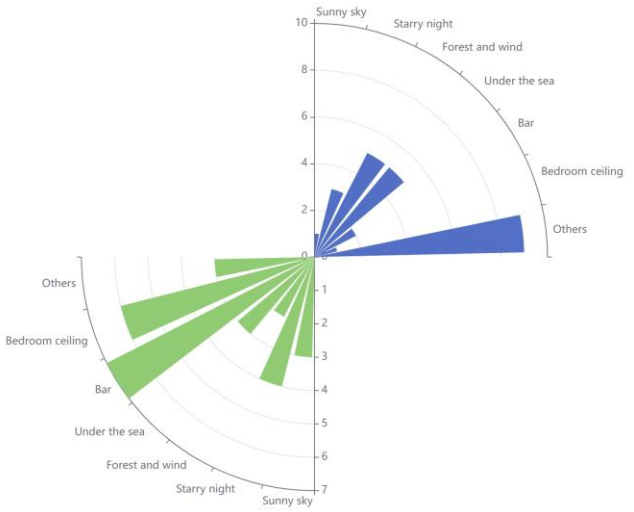


Figure 12. Test result 2

The testers' data was collected and summarised, with the results shown in Table 5. It should be noted that this collection was proactive, so there may be cases where testers have no opinion on a particular item. The following insights can be observed: (1) During daily commutes, participants dislike projections that create too significant a difference between indoor and outdoor environments. (2) An immersive atmosphere is preferred by more people. (3) In rest scenarios, the dimmer lighting of projections better aligns with the experience. (4) Projections of real-world objects are not widely accepted. (5) The rhythmic effects of music are highly appreciated.

By summarising the positive and negative views on the same video, we obtain Figure 12 (code in Appendix E), where the green bars represent negative views and the blue bars represent positive views. Therefore, in the next iteration, we discard videos where negative views far outweigh positive views, namely the real bar counter and indoor roof items.

4.5 Final iteration

When considering where to set up the projection, the control centre is the best choice, as shown in Figure 13.

The previous projection videos were updated and iterated, with poor reviews removed and good reviews added. This resulted in a final selection of nine videos, which were placed on the sunroof to illustrate the actual design concept, as shown in Figure 15.

Figure 13. Position

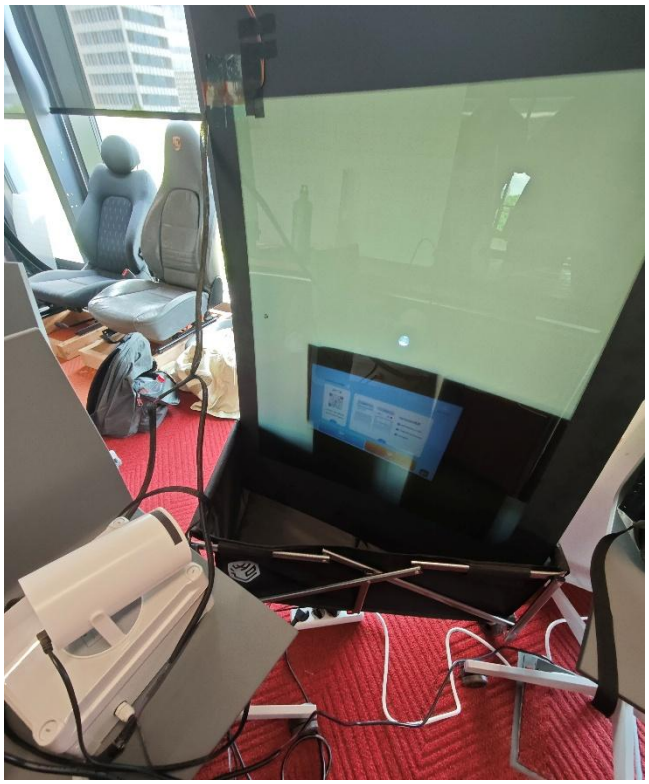


Figure 14. Demo day picture

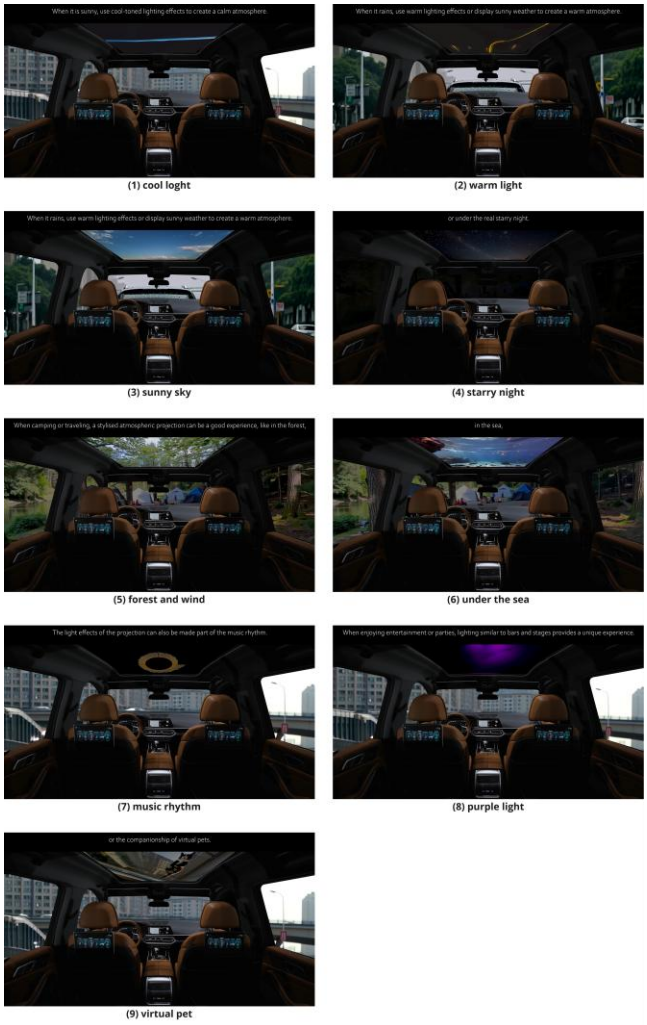


Figure 15. Final projection

They are: (1) Project cool, refreshing light effects on sunny days. (2) Project warm, cosy light effects on rainy days. (3) Project a sunny sky on cloudy or rainy days. (4) Project a realistic starry sky at night. (5) Project gentle breezes and forests while camping outdoors. (6) Project simulated underwater or aquarium scenes. (7) Synchronise projection light effects with music rhythms. (8) Projecting a dim, mysterious purple light effect for entertainment. (9) Projecting virtual pets surrounding a car.

Therefore, it can be said that these types of roof light projections in such scenarios can enhance the in-car experience to a certain extent.

The design can be operated manually or automatically. Manual operation refers not only to pressing buttons on a mobile phone or in-car screen interface, but also includes voice control and other methods of operation. It also refers to manually uploading projected videos, thereby enabling the design to be personalised. Automatic operation refers to the projection of videos that are automatically generated as needed, as well as a function that allows the car to automatically turn on or off according to the environment and preset conditions, thereby making operation more convenient.

There are three potential commercial implementation strategies for this design concept. The first is a monthly or annual subscription model, where users purchase usage time. Since the projected videos in this design are ideally generated by AI, adopting the existing pricing models of other AI services—such as monthly or annual subscriptions—could be a viable option. The second is bundled sales, where this service is bundled with other services to encourage more people to try the experience and assess its quality. The third option is to incorporate it into benefits, such as including it in member discounts or benefits. This could also be further segmented, for example, offering a low-cost version with a basic projector and a high-cost version with a premium projector, and so on.

5 Discussion

The study summarises current and near-future trends in interior and exterior vehicle lighting, discusses the possibility of using projection for roof lighting to enhance user experience, and explores implementation methods, representing an extension of interior lighting design applications.

The study has some limitations. (1) The projector used in the test was a standard model, not a high-precision projection device. The reliability, cost, and size of high-precision projection devices were not considered. (2) The testers were predominantly female, which may have compromised the rigor of the results. Additionally, the testers were primarily young Asian individuals, which may differ from automotive cultures in other regions or ethnic groups, potentially influencing the final research outcomes. (3) Due to the excessive weight of the sample, it was not possible to mount it to simulate the actual position of a car sunroof for testing, which also affects the final research results.

Future work: Future research needs to be conducted in real vehicles and real-world scenarios to explore the similarities and differences between the sunroof glass of different vehicles. It is also necessary to explore the impact of different weather conditions on projection quality, etc.

6 Conclusion

This study addresses the research question of how advanced lighting solutions in panoramic roofs can enhance the in-vehicle driving experience. For the lighting design of panoramic sunroofs, if lighting is employed, it must align with contemporary trends: namely, facilitating information exchange between occupants inside and outside the vehicle, enabling more practical interactions, achieving real-time and customisable functionality, and dynamically adapting to factors such as temperature and mood. A design that better meets the requirements of multiple scenarios is the use of PDLC glass combined with projection. This study also discusses specific scenarios and the types of projected videos that would better align with users' in-vehicle experience.

ACKNOWLEDGMENTS

I would like to thank Pavlo for his support and guidance. His advice and the thesis references he provided were very helpful. I would also like to thank Inalfa and my supervisor Sergej for their support and assistance, as well as for providing PDLC glass samples. Finally, I would like to thank the other coaches for their valuable advice during the demo day.

I acknowledge that in this research I used DEEPL to translate some Chinese words into English, and used Keling AI as a tool for test video generation in the design concept.

REFERENCES

[1] Yale Z. Wong, David A. Hensher, and Corinne Mulley. 2020. Mobility as a service (MaaS): Charting a future context. *Transportation Research Part A: Policy and Practice* 131, (2020), 5–19. DOI:https://doi.org/https://doi.org/10.1016/j.tra.2019.09.030

[2] Cars: A hands-free future. Retrieved from https://www.mckinsey.com/featured-insights/reimagining-mobility

[3] Orhan Kurtulus. 2022. An Innovative Automotive Interior Lighting Challenges. (September 2022).

[4] Global Automotive Panoramic Sunroof Market 2025 – 2034. Retrieved from https://www.custommarketinsights.com/report/automotive-panoramic-sunroof-market/

[5] Andreas Löcken, Anna Katharina Frison, Vanessa Fahn, Dominik Kreppold, Maximilian Götz, and Andreas Riener. 2020. Increasing User Experience and Trust in Automated Vehicles via an Ambient Light Display. (October 2020). DOI:https://doi.org/10.1145/3379503.3403567

[6] Starlight Headliner. Retrieved from https://www.rolls-roycemotorcars.com/content/rrmc/marketUK/rollsroycemotorcars_com/en_GB/boutique/all-accessories/starlight-headliner.html

[7] BMW i7. Retrieved from https://www.bmw.com.cn/zh/all-models/7-series/sedan/2022/7er_inspire.html

[8] Starlight Headliner. Retrieved from https://www.lzfx.com.cn/cpyjjfa/info_36.aspx?itemid=558&lcid=50

[9] USB Star Projector Night Light , Led Car Roof Lights, Portable Adjustable Interior Light, Red. Retrieved from https://www.youtube.com/watch?v=fgCTReEiacA

[10] BMW ix. Retrieved from https://www.bmw.nl/nl/modellen/bmwi/ix/bmw-ix.html

[11] SEKISUI S-LEC Glass Design. Retrieved from https://www.s-lecfilm.com/en/news/design-application/

[12] Fuyao Glass. Retrieved from https://www.fuyaogroup.com/en/products_list_12.html

[13] Zinah S.Abdulsattar. 2020. Study of the electro-chromic properties of some transition metals oxides thin films. (March 2020). DOI:https://doi.org/10.13140/RG.2.2.22693.88800

[14] DLP vs LCD vs LCoS: Projector tech pros and cons. Retrieved from https://www.cnet.com/tech/home-entertainment/dlp-vs-lcd-vs-lcos-projector-tech-pros-and-cons/

[15] Magda Kochanowska, Weronika Rochacka Gagliardi, and with reference to Jonathan Ball. 2022. *The Double Diamond Model: In Pursuit of Simplicity and Flexibility*. Springer International Publishing, Cham. DOI:https://doi.org/10.1007/978-3-030-79879-6_2

[16] Pavlo Bazilinskyy, Dimitra Dodou, and J. C. F. De Winter. 2019. Survey on eHMI concepts: The effect of text, color, and perspective. *Transportation Research Part F: Traffic Psychology and Behaviour* 67, (2019), 175–194. DOI:https://doi.org/10.1016/j.trf.2019.10.013

APPENDIX A

Detailed technical survey of car sunroof glass

Dimming glass (PDLC, SPD, Dye LC, EC, Thermochromic)
UV insulation, heat and temperature control

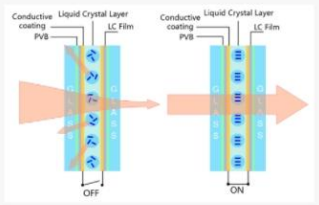
BMW ix

Customised film colours
PVB Interlayer for laminated glass

S-LEC

PDLC Dimming Glass
Cheaper and give the window a woolly-glass effect.
Personalized adjustment of the glass transparency.
Effectively enhance and protect user's privacy.

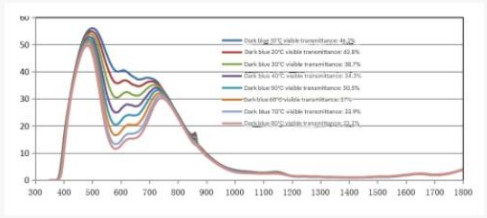
Add PDLC film between two pieces of glass, apply voltage to the terminal and change the transparency of the glass via adjusting the voltage to make the particles in the PDLC film arranged in a certain direction.



Fuyao Glass

Thermochromic Glass
Glass of various colors can be customized.
Colors will change with the temperature
Good heat insulation.

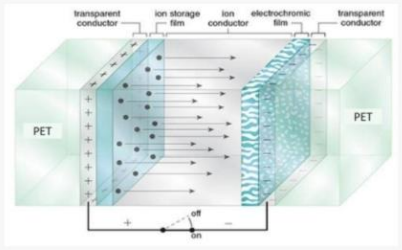
Functional particles are distributed in the PVB, which are transparent at room temperature; colorless functional particles will absorb the heat and turn into colored particles after being heated by the light or affected by the heat.



Fuyao Glass

EC Glass
Doesn't affect the light transmittance and gives the window a sunglasses-like effect.
It can automatically adjust to the intensity of ambient light to ensure a comfortable brightness in the car at all times.
The glass is much less hazy and some will be bluish.

Under the action of voltage, the optical properties (transmittance, reflectance, absorbance, etc.) of the material undergo a stable and reversible redox reaction. The commonly used electrochromic material is tungsten trioxide.



S.Abdulsattar, Zinah & Kadhim, Firas. (2020). Study of the electro-chromic properties of some transition metals oxides thin films.

SPD Glass
Due to the relatively high operating voltage, the application scenarios are more limited due to safety risks.

Particles with photo-absorbing properties are dispersed in a suspension. When no electricity is applied, the randomly arranged particles in Brownian motion can absorb more than 99% of visible light. When a voltage of 110V is applied, the particles align in an orderly fashion and light passes through.

APPENDIX B

Workshop preparation and translation

Workshop

This is a study about roof lights, about what kind of roof lights can give you a better driving experience. The initial design is to construct a varied roof light effect using projections, however, roof lights are not limited to form, so please give full play to your imagination. During the process, information about your ideas will be captured as well as photos of your participation.

Write down the conclusions of your discussion on the paper.

In the scenarios, please fully discuss your posture in the car, such as sitting, reclining or lying down.

Please describe in detail and provide reasons for the lighting effects you expect, such as colour, pattern, and specific content of the projection.

[Scenario 1]

Imagine that you are on a car journey to school. Discuss what kind of roof glass changes or interior light changes you would like to see at different times during the journey.

[Scenario 2]

Imagine that you are on a camping trip and you put the seats down to create a sleeping environment. Discuss what kind of roof glass changes or interior light changes you would like to see at different times of the day when you are resting, entertaining, or sleeping in the car.

[Scenario 3]

Imagine that you are on a long-term driving and you are playing games or singing songs with your friends using the devices in the car. Discuss what kind of roof glass changes or interior light changes you would like to see at different times of the day.

Participant 1

[Scenario 1]
Good weather with sunshine, birds (also with sound)
(Even though the weather outside is not that good.)
[Scenario 2]
It would be better to be dark. And play some ambient sound/music.
Nature.
Alarm(Light) → Like sunshine
Go back: City simulator (You're not in wilds)
[Scenario 3]
Digital Art, like pets
Animation based on music/sound (Rythm)
KTV headlight ball → without affecting driving
Game victory → ribbons flying
Respond to the shaking/movement of the content on the screen

Participant 2

[Scenario 1]
Relax my mind, some beautiful colors projection, I'd prefer no more additional information, just help me reduce my stress. There could be different topics of the projection, such as blue sky with clouds, star night, jungle...
[Scenario 2]
Resting & sleeping: low brightness, and the light can wake me up (it becomes brighter and brighter when I need to get up) + white noise
Entertaining: happy vibe + popular music, funny animation, natural environment
[Scenario 3]
Playing games: simulate the environment in the game I'm playing. It can show some visual effects when I pass or failed in the game.
Singing songs: the roof light changes with the rythm of the song, or the projection can show the MV of the song.

Participant 3

[Scenario 1]
Going to school: memorizing texts and words
Real-time animation of simulated weather
[Scenario 2]
Displayed on the roof based on the movement of people outside the car (distance, direction)

Simulate a bedroom (an environment familiar to the user)
[Scenario 3]
Music visualization, digital art
Atmosphere effects for social games (such as Werewolf, Monopoly, and board games)
Musical score and lyrics prompts (to enhance the feeling of "connection")
Digital Pets
Experience lying in a special environment (such as water, coffin...)

Participant 4
[Scenario 1]
Fragmented information, news events
Winter: warm light; Summer: cool light
After school: the lights become warm and soothing music plays
[Scenario 2]
Close to the natural environment, simulated sky, blue sky and white clouds, cheerful music, breeze in the leaves, starry sky at night
Movies in the car, the roof matches the movie content, lighting and sound
Simulate interior lighting
[Scenario 3]
According to the game type, horror games: dim lighting; entertainment and relaxation games: cheerful atmosphere
Natural environment, cool autumn weather, and a pleasant mood
Oceanarium, fish swimming

Participant 5
[Scenario 1]
Lights that can wake me up (especially in the fall and winter mornings)
Simulated/augmented weather; weather forecasts
Simulate daylight; similar to vision pro, AR experience
Combined with weather, real-time weather feedback/ambient sound/enhancement
Shopping preview, check out the shopping cart and discount information
[Scenario 2]
Entertainment: watching movies, music videos, photos
Bar: Project some environmental elements, bar counter, wine bottles...
Couples: Ambiguous and intimate atmosphere
Chatting while lying down: AVATAR for online friends
Help babies sleep: a rotating toy that simulates a cradle
[Scenario 3]
Create a concert or dance lighting scene, audience + lighting
Create an environment based on the event: Telling a story: candlelight; telling a ghost story: purple light, skull, spider web...
Open-air cinema/music festival: Each car is a unit, creating the atmosphere of the whole scene together

APPENDIX C

AI Video and Prompts

Keling AI: https://app.klingai.com/cn/text-to-video/new

Original prompt: 仰视视角的蓝天，晴天环境下的蓝天，天空非常蓝，有一点点有明确形状的白云，有不刺眼的阳光，缓慢的云朵运动
Translation: Looking up at the blue sky, the sky is very blue on a sunny day, with a few clearly shaped white clouds and gentle sunlight. The clouds move slowly. Original prompt

Original prompt: 夜间的星空，写实，仰视视角
Translation: The night sky, realistic, looking up

Original prompt: 仰视视角的树林，看见树梢上很多树叶被风吹得在晃动，绿色的树林与叶子，隐约从树叶间透出蓝天，微风吹拂，写实
Translation: Looking up at the forest, I see many leaves swaying in the wind at the treetops. The green forest and leaves faintly reveal the blue sky between them. A gentle breeze blows, creating a realistic scene.

Original prompt: 仰视视角在海底看海洋，五彩的鱼儿在游动，类似水族馆内养的鱼群，蓝色的透光的浅层的海洋，半写实
Translation: Looking up at the ocean from the seabed, colourful fish swim around, similar to the fish kept in an aquarium. The shallow ocean is blue and translucent, semi-realistic.

Original prompt: 仰视视角看卧室内的天花板，夜间环境，温馨的房间，写实
Translation: Looking up at the ceiling in the bedroom, night-time setting, cosy room, realistic.

Original prompt: 仰视视角的吧台氛围，很多酒瓶与暗紫色昏暗的灯光，适合聚会的氛围
Translation: The bar has an upward-looking atmosphere, with many bottles of alcohol and dim purple lighting, creating an atmosphere suitable for parties.

Original prompt: 黑底伴随着紫色流光效果，类似酒吧或者舞台的光效，黑色背景
Translation: Black background accompanied by purple light effects, similar to the lighting effects in bars or on stages, black background

Original prompt: 黑底伴随着浅蓝色流光效果，简单的蓝色线条形灯光，平静的感觉，黑色背景
Translation: Black background accompanied by light blue flowing light effects, simple blue line-shaped lights, a calm feeling, black background

Original prompt: 黑底伴随着淡黄色流光效果，多条简单的浅黄色线条形灯光，温馨的感觉，纯黑色背景
Translation: Black background accompanied by a pale yellow glow effect, multiple simple pale yellow lines of light, a warm feeling, pure black background.

Original prompt: 猫踩在玻璃上，从玻璃下面仰视看猫，猫走过留下猫爪印，可以看到猫肚皮，晴天
Translation: A cat steps on glass, looking up at the cat from below the glass. As the cat walks by, it leaves paw prints, and you can see its belly. It's a sunny day.










APPENDIX D

Test questionaire

1. Tester's number *

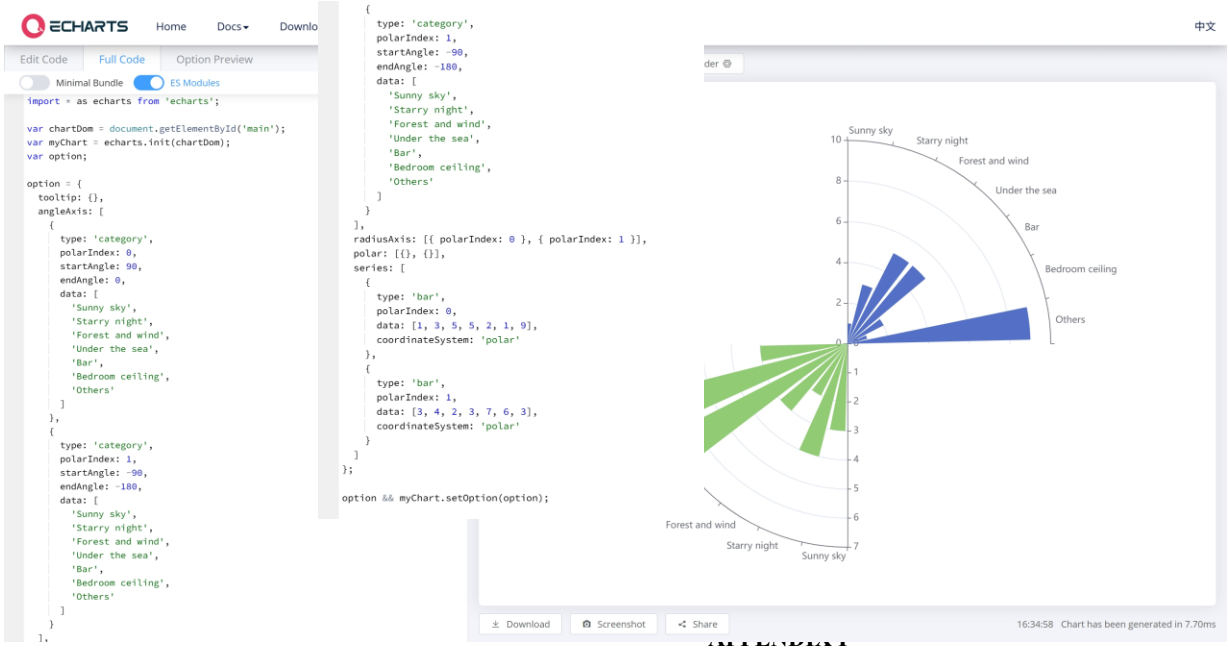
输入你的答案

2. What do you think of the whole experience of the projection? (1 is the lowest and 5 is the highest) *

	1	2	3	4	5
enjoyable	◯	◯	◯	◯	◯
understandable	◯	◯	◯	◯	◯
creative	◯	◯	◯	◯	◯
valuable	◯	◯	◯	◯	◯
interesting	◯	◯	◯	◯	◯
predictable	◯	◯	◯	◯	◯
attractive	◯	◯	◯	◯	◯
friendly	◯	◯	◯	◯	◯
efficient	◯	◯	◯	◯	◯
secure	◯	◯	◯	◯	◯

APPENDIX E

Data of the chart



APPENDIX F

ERB and consent form

Information sheet for research project "Design of advanced lighting solutions in panoramic roofs that can improve driver and passenger's driving experience"

1. Introduction

You have been invited to take part in research project Design of advanced lighting solutions in panoramic roofs that can improve driver and passenger's driving experience,because you are invited by personal network.

Participation in this research project is voluntary: the decision to take part is up to you. Before you decide to participate we would like to ask you to read the following information, so that you know what the research project is about, what we expect from you and how we deal with processing your personal data. Based on this information you can indicate via the consent declaration whether you consent to take part in this research project and the processing of your personal data.

You may of course always contact the researcher Xinyue Liu via *x.liu2@student.tue.nl*, if you have any questions, or you can discuss this information with people you know.

2. Purpose of the research

This research project will be managed by Xinyue Liu. *Optional:* The research project is a collaboration between TU/e, and Inalfa.
The purpose of this research project is to fidure out how can advanced lighting solutions in panoramic roofs improve driver and passenger's driving experience.

3. What will taking part in the research project involve?

You will be taking part in a research project in which we will gather information by:

- Asking you to visit a location 1 time so we can interview you about [experience after each projected content or different scenarios in test
- Interviewing you about experience after each projected content or different scenarios in test and to write down/record your answers via audio/video. Also, we will make a transcript of the interview.
- Observation
- .....

This study will be completely anonymous, and the data obtained from the study will not be traceable to you.

For your participation in this research project you will not be compensated.

4. Potential risks and inconveniences

Your participation in this research project does not involve any physical, legal or economic risks. You do not have to answer questions which you do not wish to answer. Your participation is voluntary. This means that you may end your participation at any moment you choose by letting the researcher know this. You do not have to explain why you decided to end your participation in the research project. Ending your participation will have no disadvantageous consequences for you.

If you decide to end your participation during the research, the data which you already provided up to the moment of withdrawal of your consent will be used in the research. Do you wish to end the research, or do you have any questions and/or complaints? Then please contact Xinyue Liu via *x.liu2@student.tue.nl*.

5. Confidentiality of data

The raw and processed research data will be retained for a period of 1 year. Ultimately after expiration of this time period the data will be either deleted or anonymized so that it can no longer be connected to an individual person. The research data will, if necessary (e.g. for a check on scientific integrity) and only in anonymous form be made available to persons outside the research group.

This research project was assessed and approved on 2-5-2025 by the ethical review committee of Eindhoven University of Technology.

***** Scroll down for the consent form *****