An E-Scooter Design with Enhanced Intent Legibility for Mixed Urban Traffic

Master Thesis

Industrial Design Engineering

Integrated Product Design

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Acknowledgments

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Excecutive Summary

Micromobility vehicles (MMVs) – lightweight vehicles such as bicycles, e-bikes, and (e-)scooters have emerged as an increasingly prominent urban transportation mode, and are expected to constitute a substantial part of future traffic systems. However, their growing presence introduces safety concerns to both MMV riders and surrounding road users (RUs), as MMV interactions often exhibit uncertainty regarding their behavior or intent. Among them, e-scooters – as a relatively new type of MMV – pose particularly significant challenges due to their maneuver flexibility, variable rider behaviors, limited signaling measures, and frequent space sharing, while unfamiliarity with them exacerbates these challenges. While existing measures primarily focus on infrastructure design, regulatory enforcement, and behavioral education, little attention has been given to vehicle-based solutions.

This thesis presents a Research-through-Design project that explores how vehicle embodiment, including physical form and dynamic elements, can support the intent legibility of an e-scooter during traffic interactions. The objective is to develop an e-scooter design with functions and features that enable interacting RUs to perceive the rider's intent more accurately and promptly, therefore improving both objective and perceived safety in mixed urban traffic.

A literature review and interaction analysis identified critical intents in key interaction scenarios, and precedent research provided a theoretical basis and design inspiration, which informed the subsequent iterative design exploration. The final outcome is a proposed e-scooter design with enhanced intent legibility through its static form and dynamic lighting. Vehicle-based features and two form variations created by light and shadow effects improve predictability by aligning general expectations with the vehicle's behavioral characteristics, which serves as an implicit communication layer. Explicit light signals adopt both conventional signals and newly designed priority signals building on perceptual associations. Together, the light elements improve the vehicle's detectability and directionality, also providing explicit intent communication in relevant scenarios.

A user study evaluated the form transformation and explicit priority signals. The results suggested that the form transformation successfully influenced behavioral expectations in the intended direction regarding the likelihood of traveling at a high speed, exhibiting greater maneuverability, and claiming priority during interactions. However, it did not bias intent interpretation in unsignalized crossing encounters. The yielding signal demonstrated potential in supporting yielding intent perception, while the proceeding signal produced inconsistent interpretations. The findings indicated that further refinement should prioritize existing traffic-related associations, and establish stronger and more distinguishable semantic associations. In general, there is an increase in the ease of interpretation ratings with the presence of explicit signals, suggesting that they can potentially facilitate intent interpretation by improving the salience of communicative cues.

The proposed design demonstrates its technical feasibility to be realized as a next-generation mobility product, although further ergonomics research, engineering development and valida-tion are required before implementation.

Beyond the proposed design itself, the project demonstrates a systematic approach to enhance intent expression through vehicle embodiment. The resulting communication strategy and findings can inform design and research for future e-scooter development, offer transferable insights for other MMVs and the broader mobility field on improving intent communication in mixed traffic environments.

AI Statement: ChatGPT was used for grammar checking, sentence refinement, and improving the overall flow and clarity of the writing. All ideas and analyses are original to the author.

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1 Introduction

Micromobility vehicles (MMVs) – lightweight vehicles such as bicycles, e-bikes, skates, and (e-)scooters have emerged as an increasingly prominent inner-city transportation mode (NACTO, 2019; Sanchez et al., 2020; Santacreu et al., 2020). Because of their compactness, portability, and insensitivity to traffic jams, they play an important role in short-distance urban commutes (Olabi et al., 2023) and facilitating first- and last-mile connections to public transport (POLIS, 2019). Their lower environmental impact and contribution to increased active mobility use further align them with the Sustainable Development Goals (SDGs) (Olabi et al., 2023). Additionally, predictive studies indicated that despite the increasing penetration of autonomous vehicles, active transport and public transport, should still be prioritized to ensure mobility sufficiency in urban environments (Snelder et al., 2025; Soteropoulos et al., 2021). Therefore, MMVs are expected to constitute a substantial part of future traffic systems.

Figure 1.2: Imaginary urban traffic with increased micromobility vehicles co-existing with motor vehicles. Source: https://www.weareacuity.com/local-thinking-our-blog/micromobility

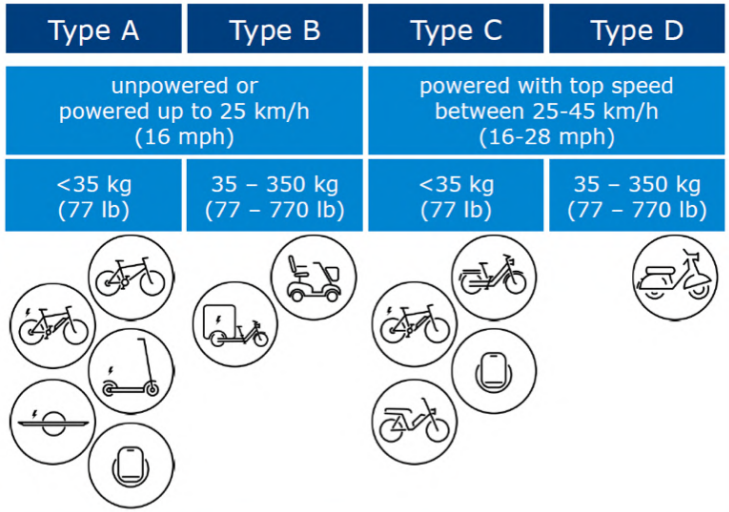


Figure 1.2: Proposed micromobility definition and classification (Santacreu et al., 2020).

However, the growing presence of MMVs introduces safety concerns to both MMV users and interacting road users (RUs). Vulnerable road users (VRUs) – including pedestrians and MMV users– are inherently exposed to a greater risk of injury or death due to the absence of protection by an outside shield (National Safety Council, 2018). Crashes between MMV riders and motor vehicles were the most frequent circumstance among MMV injury events and with more severe injuries (Fang, 2022). At the same time, conflicts and injuries involving pedestrians remain a concern, particularly with the rapid growth of e-scooter use (Chong et al., 2010, as cited in Mesimäki & Luoma, 2021; Fonseca-Cabrera et al., 2021). Near accidents occur considerably more frequently than collisions (Poulos et al., 2017). A near accident, sometimes referred to as a conflict, is a situation in which at least one participant became frightened, was forced to evade, or brake forcefully to avoid a collision (Mesimäki & Luoma, 2021). Near accidents can be seen as indicators of underlying risks, and can negatively affect the perceived feeling of safety among RUs. Many studies further indicate that many of these safety-critical events occur more often in shared spaces between different types of RUs. Compared to separated infrastructure, accidents, injuries, and near accidents occur more frequently on shared pedestrian-cyclist paths and similar mixed-use environments (Beck et al., 2016; De Rome et al., 2014, as cited in Mesimäki & Luoma, 2021; Poulos et al., 2017). In many urban environments, pedestrians and MMVs co-exist in

shared paths and sidewalks (Šucha et al., 2023; Zhang et al., 2023), which increases interaction frequency, raising the likelihood of safety-critical situations.

Taken together, these findings indicate that such safety-critical events are associated with interactions between RUs. Safe interaction in traffic relies on the correct anticipation of each other's behavior enabling timely responses and avoiding potential conflicts (Petersen & DeLucia, 2026; Westerhuis & De Waard, 2017). Correct intent predictions are typically based on perceptible cues such as movement patterns, social cues, or explicit signals. Failures in recognizing relevant information (Chaloupka-Risser & Füssl, 2017), misunderstanding of behaviors (Uttley et al., 2020), and inadequate signal use or unpredictable behaviors (Karlsen & Bjørnskau, 2020) often lead to inaccurate judgments of intentions, causing potential accidents (Bjorkman et al., 2008, as cited in Petersen & DeLucia, 2026) and lower perceived safety for RUs (Karlsen & Bjørnskau, 2020). This may in turn influence the RU's own behavior, such as aggressive driving (Song et al., 2023) or rule-breaking (Kaiser et al., 2016; Precht et al., 2017, as cited in Karlsen & Bjørnskau, 2020), introducing additional risks and potentially discouraging the use of active transport modes.

To facilitate the integration of MMVs into the current traffic system, it is therefore important to address the challenges concerning the communication between them and other road users. Figure 1.3 gives a schematic overview of the communication of intent between MMVs and other road users.

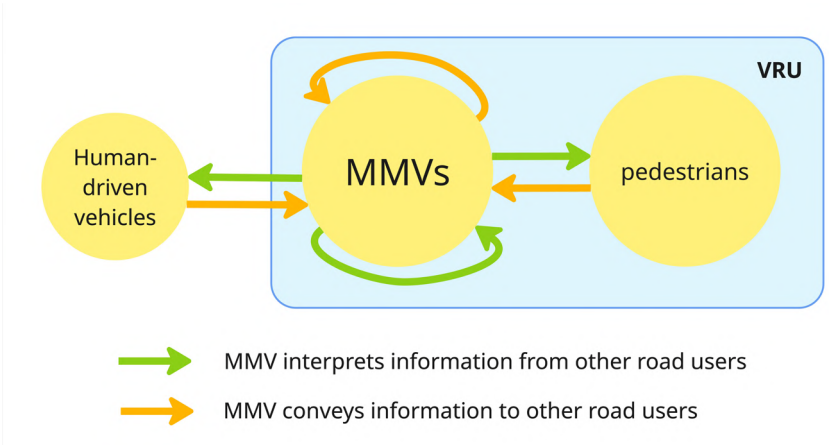


Figure 1.3: Communication links involving MMV in mixed traffic scenarios.

Through a literature review that examines communication mechanisms and challenges in intent perception in traffic interactions involving MMVs, it was found that communication involving e-scooters is particularly problematic. An e-scooter, sometimes referred to as an electric kick scooter, is a stand-up scooter powered by an electric hub motor, with a large center deck where the rider stands (Wikipedia, 2024). Due to their maneuver flexibility, variable rider behaviors, limited signaling measures, frequent space sharing, and unfamiliarity with them, e-scooters pose more significant challenges in intent perception during traffic interactions. As the second most widespread MMV mode (Hardt & Bogenberger, 2019, as cited in Fonseca-Cabrera et al., 2021), improving intent communication in e-scooters emerges as a meaningful entry point to address MMV-related interaction challenges.

Figure 1.4: E-scooter examples. Source: https://www.popsci.com/gear/best-electric-scooters-for-adults/

This project investigates how the physical embodiment of an e-scooter – including form language and integrated dynamic lighting – can enhance the legibility of vehicle intent in traffic interactions. Through literature research, interaction analysis, and iterative design exploration, the project aims to develop an e-scooter design proposal with functions and features that allow interacting RUs to perceive the rider's intent more accurately and promptly, thus improving both physical and perceived safety for RUs in mixed traffic environments.

2 Literature Review:
Communication challenges involving micromobility vehicles in traffic interactions

This literature review examines communication mechanisms and challenges in intent perception in traffic interactions involving MMVs. The aim is to identify where design interventions may add value, informing the design of an MMV with enhanced communication strategies that improve road safety and efficiency.

2.1 Current Communication Mechanisms in Traffic

Common communication methods can be categorized into explicit and implicit communication (Harkin et al., 2024), and different communication cues are employed depending on the road users involved and the interaction context.

2.1.1 Explicit communication

Explicit communication involves the deliberate transmission of signals to convey a specific message (Harkin et al., 2024). Eye contact is a major explicit communication channel, which is commonly used to negotiate priority (Karlsen & Bjørnskau, 2020). Other common explicit cues include gesture-based signals, such as hand waves to yield or thank, nodding, or hand signals by cyclists to indicate turning (Petersen & DeLucia, 2022). Some pedestrians may also raise their hand or finger to indicate their intention to cross the road (Dey & Terken, 2017). It also includes vehicle-based signals including lights (e.g., headlights, turn signals, brake light, hazard light) and the horn, which is the main communication channel in motorized traffic (Uttley et al., 2020).

2.1.2 Implicit communication

Implicit communication refers to the transmission of signals without intentionally conveying a specific message (Harkin et al., 2024). A pedestrian's body language (e.g., body turning, head/leg motions) is essential for accurate predictions of their intent (Petersen & DeLucia, 2022). Head movements and the posture of the bicyclist on the bicycle (leans or sits up straight), position on the road, can indicate intention to turn. For both bicycles and motor vehicles, motion patterns and speed change are important indicators of their intention to turn or yield (Petersen & DeLucia, 2022). Observational studies (Dey & Terken, 2017; Lee et al., 2020; Uttley et al., 2020) suggest that kinematic cues of vehicles (such as distance, speed, braking) play a significant role for pedestrians in efficient traffic negotiations.

2.1.3 The use of communication cues in different interaction scenarios

Pedestrian-driver interactions

road users predominantly rely on implicit kinematic cues such as vehicle speed and distance to decide on road crossing, while explicit cues such as eye contact or head/hand movements are rarely used (Dey & Terken, 2017; Lee et al., 2021). In turn, the intentions of the pedestrians are typically inferred by drivers from gait, head orientation, and movement patterns that implicitly convey their situational awareness (Dey & Terken, 2017). However, findings regarding the role of eye contact remain mixed, with some studies suggesting that it helps confirm priority during interactions (Schneemann & Gohl, 2016, as cited in Petersen & DeLucia, 2022; Uttley et al., 2020).

Cyclist-driver interactions

Explicit communication cues play a more prominent role. Cyclists commonly establish eye contact and use hand gestures, relying on explicit cues from drivers to know their intent (Al-Taie et al., 2022). An observational study by Al-Taie et al. (2023) discovered that the specific communication cues used by cyclists and drivers vary by scenarios: At uncontrolled intersections, road users adopt a combination of deceleration, gestures, facial expressions, and vocal cues, whereas at roundabouts and controlled intersections, cyclists rely more on hand gestures and head movements, while drivers primarily communicate intent through on-vehicle signals (Al-Taie et al., 2023). Despite this, yielding decisions and crossing safety are negotiated based on speed, temporal characteristics, and relative position (Harkin et al., 2024; Zhang et al., 2022).

MMV-pedestrian interactions

In MMV-pedestrian interactions, speed-related variables are the most significant predictors of cyclist behavior at a zebra crossing (Nasseredine, 2025). In shared lanes, e-scooter riders employ a wide range of strategies to alert others in shared spaces, including bells, verbal cues, and hand gestures (Kegalle et al., 2025b). Observational studies further illustrate how negotiation between e-scooter riders and pedestrians relies heavily on sequential and reciprocal interpretation of implicit cues. For instance, a pedestrian may convey recognition through gaze and stopping behavior, and conversely, the e-scooter decelerates to indicate recognition and yielding, and both would accelerate to show appreciation if the other yielded (Tuncer & Brown, 2020).

Driver-driver interactions

In driver-driver interactions, vehicle-based signals are more common, while interpersonal cues are infrequent (Uttley et al., 2020). Nevertheless, hand gestures may still be used by drivers to determine if they should yield or go when interacting with another driver (Kitazaki & Myhre, 2015, as cited in Petersen & DeLucia, 2022), and even be a strong enough cue to make drivers yield or stop even if they had priority (Petersen & DeLucia, 2022).

2.2 Challenges in MMVs Interactions

Most existing studies involving micromobility interaction focus on specific vehicle types, mainly bicycles and e-scooters. Insights related to key interaction characteristics, including small vehicle size, limited physical protection, and reliance on rider behavior for signaling, are transferred to general MMV interaction, and vehicle-specific characteristics were also addressed.

2.2.1 Challenges in MMV-VRU interactions

Unawareness of MMV presence

A recurring challenge in MMV–VRU interactions is pedestrians' delay or failure to perceive approaching MMVs. Pedestrians frequently report (e-)scooters or cyclists approaching silently or abruptly from behind as unsettling (Karlsen & Bjørnskau, 2020; Sudhakaran et al., 2025). Crash and conflict analyses indicate that inattention of both pedestrians and cyclists is the most common contributing factor to collisions (Loukaitou-Sideris et al., 2014, as cited in Zhang et al., 2023). Distraction sometimes further exacerbates the unawareness, such as mobile phone use or headphones, which were proven to reduce pedestrians' ability to notice approaching MMVs (Kegalle et al., 2025a). Another problem with e-scooters and bicycles reported by other VRUs is their low visibility due to inadequate lighting (Kegalle et al., 2025a; Sudhakaran et al., 2025).

Lack of effective signals

Formal arm signals of cyclists are sometimes absent, and their intent can be incorrectly predicted when using informal cues. From the MMV users' perspective, e-scooter riders reported that effectively notifying other road users of their presence and intention to turn is a major challenge, because of the lack of indicators, hand-signal turns causing instability, and bells were often ignored or failed to elicit a response (Kegalle et al., 2025a). This often leads to road users getting in the way, reducing efficiency for MMV users, and increasing perceived risk for both parties (Kegalle et al., 2025a).

Right-of-way conflicts

Conflicts related to right-of-way are another frequently reported issue in MMV–VRU interactions. Expectations that cyclists will yield to pedestrians at crossings are not always met (Nassereddine et al., 2025), and cyclists failing to give way to pedestrians is identified as the most common issue in cyclist-pedestrian interactions (Mesimäki & Luma, 2021).

Unpredictable movements

Pedestrians and MMVs have a high degree of movement flexibility (Zhang et al., 2023), which is a nuisance for both parties (Sudhakaran et al., 2025). Cyclists often swerve or alter speed to avoid yielding, which can surprise pedestrians and lead to unsafe situations (Nassereddine, 2025). E-scooters are often considered particularly problematic due to their distinct maneuvering patterns: They are more likely to weave through pedestrian traffic, more prone to closer interactions (Kegalle et al., 2025a), and sometimes transition between different road spaces (Tuncer & Brown, 2020), or overtake without explicit warning (Kegalle et al., 2025a). This creates potential conflicts with pedestrians and cyclists and increases pedestrians' feelings of vulnerability. Conversely, erratic movements of pedestrians, particularly children and the elderly, were seen as a safety concern by MMV users (Kegalle et al., 2025a; Sudhakaran et al., 2025), with unexpected maneuvers identified as a leading cause of conflicts and near misses between cyclists and pedestrians (Mesimäki & Luoma, 2021).

Speed

Excessive speed of MMV users is another major safety concern reported by VRUs interacting with MMVs (Sudhakaran et al., 2025). Zhang et al. (2023) argued that pedestrians' perceived risk increased with MMVs' speeding up in shared space. It is also identified as a major cause of near accidents between MMVs and pedestrians (Dozza et al., 2016, as cited in Zhang et al., 2023; Mesimäki & Luoma, 2021).

2.2.1 Challenges in MMV-driver interactions

Ambiguity in communication cues

Communication cues from MMV users can sometimes be misinterpreted or cause uncertainty directly. Empirical studies show that hand signals vary in recognition accuracy depending on gesture type, and are sometimes interpreted differently or incorrectly (Petersen & DeLucia, 2022). Behaviors such as a bicyclist glancing over their shoulder are found to be confusing for interacting drivers (Petersen & DeLucia, 2022). Drivers may incorrectly predict a cyclist's intentions when relying on implicit cues. In contrast, clear arm signals were proven to convey intentions more clearly than ambiguous or no signal (Petersen & DeLucia, 2022; Crowley-Koch et al., 2011, as cited in Uttley et al., 2020). Conversely, when the communication cues from drivers are insufficient or considered unclear, interacting VRUs may feel unsafe or frustrated, for instance, failing to make eye contact when negotiating the way (Karlsen & Bjørnskau, 2020) or when drivers failed to stop significantly short to yield (Risto et al., 2017, as cited in Petersen & DeLucia, 2022).

Right-of-way expectations mismatch

Right-of-way conflicts constitute one of the most critical safety challenges in MMV–driver interactions. Many motorists reported experiencing cyclists who fail to yield when they should, and many cyclists say the same about motorists (Karlsen & Bjørnskau, 2020). Injured cyclists frequently report assuming that drivers would yield according to the rules, revealing a gap between legal expectations and drivers' actual yielding behavior (Zhang et al., 2022).

Visibility

Visibility is a challenge also in MMV-vehicle interactions, especially in low-light conditions. Both motorists and VRUs consider the other party not using lights or reflective items in the dark as the most problematic behavior (Karlsen & Bjørnskau, 2020).

Driver behavior

MMV users often view driver behavior itself as a safety risk. Motor vehicles often drive fast and sometimes unpredictably, making it difficult and dangerous for e-scooter riders and cyclists (Tuncer & Brown, 2020). Moreover, car drivers are more likely to yield at crosswalks for cyclists than for e-scooter riders, reflecting different acceptance across MMV types (Pils et al., 202; Kegalle et al., 2025b).

2.3 Underlying Causes

2.3.1 System-level factors

Infrastructure

In many urban environments, pedestrians and MMVs co-exist in shared lanes (Šucha et al., 2023; Zhang et al., 2023). The study by Mesimäki & Luoma (2021) reported that near accidents most frequently occurred on shared pedestrian and bicycle paths. In addition, places without clear rules or behavioral norms, such as unsignalized road sections, increase interaction frequency and uncertainty, leading to a higher likelihood of conflicts (Al-Taie et al., 2023; Kaparias et al., 2012, as cited in Uttley et al., 2020).

Road users volume and variety

Zhang et al. (2023) identified that differences between pedestrians and various types of MMVs in terms of size, power, speed, and kinetic energy result in complicated and dynamic traffic flows and interactions, and that high traffic volume and traffic complexity were two key triggers of conflict.

Regulatory ambiguity

Particularly concerning e-scooters, relevant regulations vary significantly across localities (Tuncer & Brown, 2020). With the absence of clear, strict legislation, e-scooters exhibit unrestricted behavior, while other road users lack a shared reference for expectations, rights, and obligations (Tuncer & Brown, 2020).

2.3.2 MMV design level factors

Lack of vehicle-based signals

Many MMVs lack standardized vehicle-based signaling systems, such as turn indicators or sufficient lighting, due to design constraints and the absence of

established usage standards. The use of vehicle-based signals has been proven to support effective priority negotiation in motorized traffic (Uttley et al., 2020), suggesting their absence on MMVs limits the clarity and consistency in intention communication. Additionally, low noise emission reduces their detectability, leading to unawareness by other road users (Walton et al., 2023, as cited in Kegalle et al., 2025a).

Unique maneuvering characteristics

Certain MMV types, especially e-scooters, exhibit maneuvering characteristics that differ substantially from those of bicycles in terms of speed, acceleration, maneuverability, and riding posture (Kazemzadeh & Sprei, 2022, as cited in Kegalle et al., 2025a). These characteristics introduce behavioral variability that complicates prediction by other road users, increasing the potential for conflicts.

Riding posture

Due to the upright standing posture of the rider and the overall slim profile, e-scooters are likely to be perceived as pedestrians in peripheral vision (Tuncer & Brown, 2020). This perceptual ambiguity may delay recognition of the vehicle's speed and trajectory, leading to misjudgments in shared spaces.

2.3.3 Social- and human-level factors

Lack of experience, knowledge, and shared norms

Specifically to e-scooters, lack of knowledge in their motion characteristics contributes to perceived risk and difficulty in understanding their behaviors, often causing pedestrians to become hesitant and react haphazardly during interactions (Tuncer et al., 2020). Non-users tend to attribute accidents primarily to e-scooter behaviors and perceive interactions with e-scooters as more dangerous than do riders themselves (Šucha et al., 2023). Similarly, non-riders rate e-scooter riders as engaging in riskier and more disruptive practices than cyclists (Useche et al., 2022, as cited in Kegalle et al., 2025a).

Behavioral variability and compliance

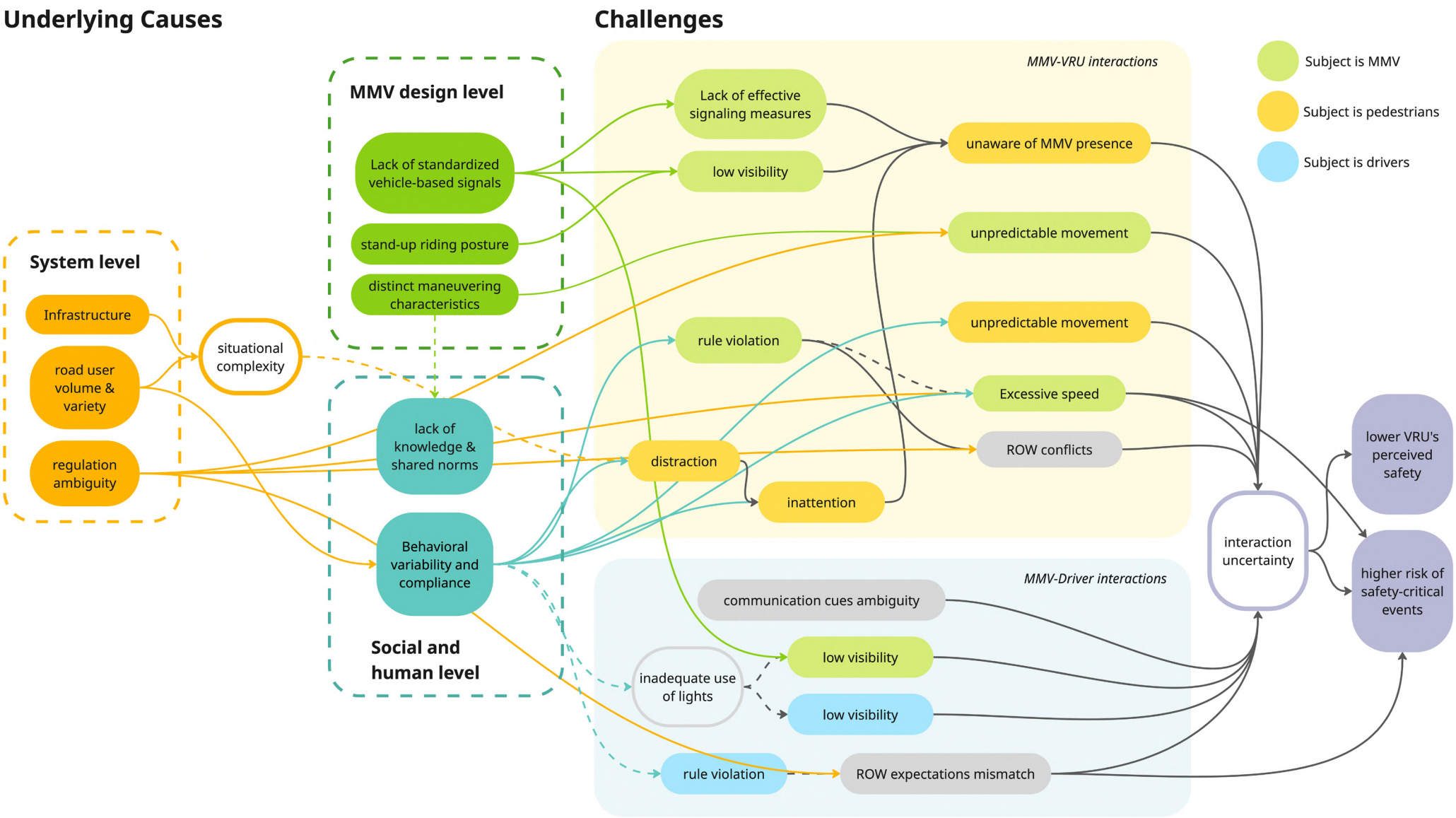
Pedestrians and MMVs have flexible movement preferences and abilities, which lead to diverse and complex behavioral characteristics (Zhang et al., 2023). Variability in attention, maneuvering behavior, and rule compliance contributes to interaction uncertainty and underlies challenges such as unpredictable movements and right-of-way conflicts. Rule violations of cyclists, particularly, lead to ROW conflicts and are a leading cause of near accidents between cyclists and pedestrians (Mesimäki & Luoma, 2021) as well as safety concerns for VRUs (Sudhakaran et al., 2025). Despite the establishment of standard arm signals, cyclists often do not use such active forms of communication in real-world scenarios.

Overall, these underlying causes strengthen each other, leading to the communication and interaction issues in MMV-related traffic interactions. A diagram representing the causal links is presented in Figure 2.1.

2.4 Proposed solutions

Many studies on reducing conflicts between MMV users and pedestrians proposed solutions, most of which target system- or human-level factors. One of the most common approaches proposed was infrastructure level, including using separate lanes for pedestrians and MMVs (Šucha et al., 2023; Mesimäki & Luoma, 2021), or visual segregation for shared paths and roads (Zhang et al., 2023). Implementing suitable regulations for lane use and speed limits for MMVs, as well as enhancing education to encourage safe riding behaviors, are also frequently proposed (Karlsen & Bjørnskau, 2020; Zhang et al., 2023). While systematic improvements are essential, they typically require long-term changes (Kegalle et al., 2025a), suggesting that vehicle-level interventions may act as a complementary or transitional solution.

Relatively few studies addressed how vehicle-level designs can support clearer intent communication. Kegalle et al. (2025b) proposed using technological solutions, such as rider assistance, collision detection, and footpath detection systems, to foster safer road interactions. Kegalle et al. (2025a) explored the use of an automatic signaling system to enhance the detectability of an e-scooter by testing user acceptance of different kinds of audio and visual alerts, which demonstrated the potential of vehicle-level interventions to actively support MMV detectability.



Note: this diagram only includes challenges covered in the reviewed literature and were identified as a great concern or major contributor to safety critical events. It does not represent all the causal relationships in traffic interactions. The causal relationships presented are based on literature and author's analysis.

Figure 2.1: Causal links between underlying causes and challenges in MMV-relevant interactions in mixed traffic context

2.5 Discussion and Conclusion

The reviewed literature indicates that intent perception in traffic relies on certain types of cues, varied by interaction contexts. When these cues are absent, ambiguous, or difficult to interpret, road users may form incorrect expectations about others' behavior. Challenges appear more diversely and frequently between MMV and other VRUs due to space sharing. Surface-level challenges often converge into interaction uncertainty, impairing road users' ability to anticipate and react to others' behavior. Across contexts, **improving visibility and predictability** emerges as a central principle for enhancing traffic communication, which aligns with earlier work by Chaloupka et al. (2011, as cited in Chaloupka-Risser & Füssl, 2017). The discussed challenges are attributed to multi-leveled and interconnected causes. System-level factors create the situational complexity that underlies many of the interaction challenges, and further lead to failures in current communication methods, while design- and human-level limitations further amplify these challenges, particularly in interactions involving unfamiliar MMV types like e-scooters, where limited experience and shared norms increase uncertainty in interpreting their behaviors. Proposed measures revealed **a lack of vehicle-based solutions**, suggesting the potential for exploration in this direction.

3 Project Brief

3.1 Problem Definition

As e-scooters are becoming an increasingly prominent mobility mode in urban traffic, interactions between e-scooter users and other road users frequently involve uncertainty about each other's intentions and future actions. Due to its maneuver flexibility, limited explicit signaling measures, frequent space-sharing, and unfamiliarity with them, safety-critical information is often absent, ambiguous, or misinterpreted. As a result, both e-scooter riders and interacting RUs may misjudge situations or fail to respond in time, increasing safety risks and reducing perceived safety.

These challenges are particularly relevant in mixed and shared urban environments, where pedestrians, cyclists, drivers, and e-scooter users frequently interact with each other and have to negotiate priority within limited space. Addressing these challenges is essential in ensuring safe and smooth integration of e-scooters into the traffic system in the near future, and further supporting sustainable mobility transitions by promoting active mobility modes and public transport.

While many solutions are proposed, they mainly focus on long-term transformations through infrastructure redesign, regulation enforcement, and behavioral education, revealing a gap in vehicle-level interventions that directly improve e-scooter-related communication challenges.

3.2 Objectives

The project focuses on **vehicle-level factors** that contribute to the interaction challenges involving e-scooters.
The literature review suggests two design directions for vehicle-level solutions:
1) enabling the MMV to signal the user's intention to enhance predictability for others, and
2) detecting and predicting the movement of surrounding road users to alert the MMV user or adjust their maneuver through automated functions.

The second direction will largely rely on sensing, prediction, and rider-assistance systems, shifting the focus toward automation-driven system behavior rather than vehicle embodiment. It also introduces practicality concerns, considering the data processing complexity and energy consumption in a lightweight vehicle. Therefore, this project focuses on the first direction – improving outward communication of e-scooter intent through vehicle-level intervention. This enables tangible and controllable intervention and aligns with the scope of a product design graduation project.

Within this direction, this project prioritizes strengthening and clarifying the cues that road users already rely on in intent perception in traffic, rather than introducing entirely new communication languages. This is because building on existing mental models may reduce cognitive load and support more intuitive interactions. Therefore, this project will explore **how existing perceptual cues (e.g., speed change, posture, trajectory) can be expressed or amplified through vehicle embodiment**, and additional signals will only be considered where such cues alone are insufficient.

In summary,

This project explores how the physical embodiment of an e-scooter, including form language, posture, and integrated dynamic elements, can enhance the legibility of vehicle intent during interactions in mixed urban traffic. The aim is to reduce interaction uncertainty, improving both physical and perceived safety for all road users.

The project is positioned as a **next-generation mobility design**, addressing both desired features and its practicality. The design prioritizes technologies and interaction principles that are technically and productionally feasible in the near future.

The final outcome is an e-scooter design with features and functions that can support its intent legibility to interacting RUs. The concept will be demonstrated using digital visualizations, including renderings, illustrations, and videos.
This design is expected to enhance the interaction experience and improve e-scooter acceptance in urban traffic. Furthermore, the project may generate transferable insights for future mobility product development regarding how intent communication can be improved through form-based design in mixed traffic environments.

3.3 Approach

The project follows a research-through-design (RtD) process. It begins with a literature review on the communication challenges involving MMVs in urban traffic, which analyzes underlying causes, identifies where design interventions may add value, and identifies e-scooters as a meaningful intervention focus.

A scenario-based mapping and a visual analysis of existing MMV types are then conducted to examine how intents are currently communicated, where communication breakdowns occur in e-scooter contexts, and identify vehicle-based design opportunities to strengthen behavioral legibility.

A precedent research is conducted to explore intent expression strategies, accompanied by explorative ideation. Design concepts will be generated through a mixed approach of ideation, iterative sketching, 3D modeling, and physical prototyping. Early design concepts are evaluated through controlled user testing with renders to support the selection of design options and validate their effectiveness.

The final integrated design will be presented through visuals such as renders, diagrams, and videos, supported by a scaled prototype and mock-ups to demonstrate the intended effects.

4 Scenario Mapping

The literature review suggests that the critical intents that need to be perceived in traffic are context dependent. Therefore, this chapter analyzes existing traffic cues and how they fail in representative or critical interaction scenarios.

4.1 Existing Traffic Cues

To provide a framework for analyzing how current cues might be relied on and fail in MMV contexts, perceptual cues that road users currently rely on to infer intent in traffic are summarized and categorized.

Figure 4.1: Examples of current intent communication cues in traffic.

Table 1: Categorization of current cues for intent interpretation in traffic interactions.

	Kinematic cues	Vehicle-based signals	Human-embodied cues
Visual	Speed Speed change (Acceleration/ deceleration) Trajectory Distance	Headlights Indicators Brake lights ...	Head movement (e.g. turning, nodding) Hand gestures (e.g. wave) Arm signals Body language (e.g. leg movements, posture) Eye contact
Auditory	/	Horn, Bell Vehicle noise	Verbal cues

4.2 Communication Breakdowns

This section maps how e-scooter behavioral cues are currently expressed and interpreted in critical interaction scenarios involving MMVs, and how they become defective.

The scenarios are selected based on representative traffic interaction situations and documented cases of challenging interactions between RUs. Based on what cues they typically refer to for intent prediction, and previously analyzed challenges and causes in MMV interactions, we analyze how these cues could potentially fail in e-scooter contexts. This mapping aims to identify **which intents are crucial to be communicated clearly**, where **e-scooter embodiment weakens cue mechanisms**, and further inform **design directions**.

Scenario 1: Shared spaces

Figure 4.2: An e-scooter rider sharing space with other road users. Source: Adobe Stock.

E-scooters often co-exist with other VRUs in urban settings (Šucha et al., 2023; Zhang et al., 2023), where they often swerve through pedestrians and overtake them. The slim vehicle profile, stand-up riding posture, and low noise level weaken their vehicle identity, making them less noticeable among pedestrians. Insufficient lighting further reduces their detectability in low-light conditions. In order to alert others in shared spaces, e-scooter riders employ a wide range of strategies, including ringing bells, verbal cues, and hand gestures, suggesting a lack of consistent signaling behavior (Kegalle et al., 2025a). Additionally, their high speed and flexible maneuverability decrease the time available for people to perceive their presence and react. These constraints together lower and delay the awareness of people during e-scooter interactions in shared spaces.

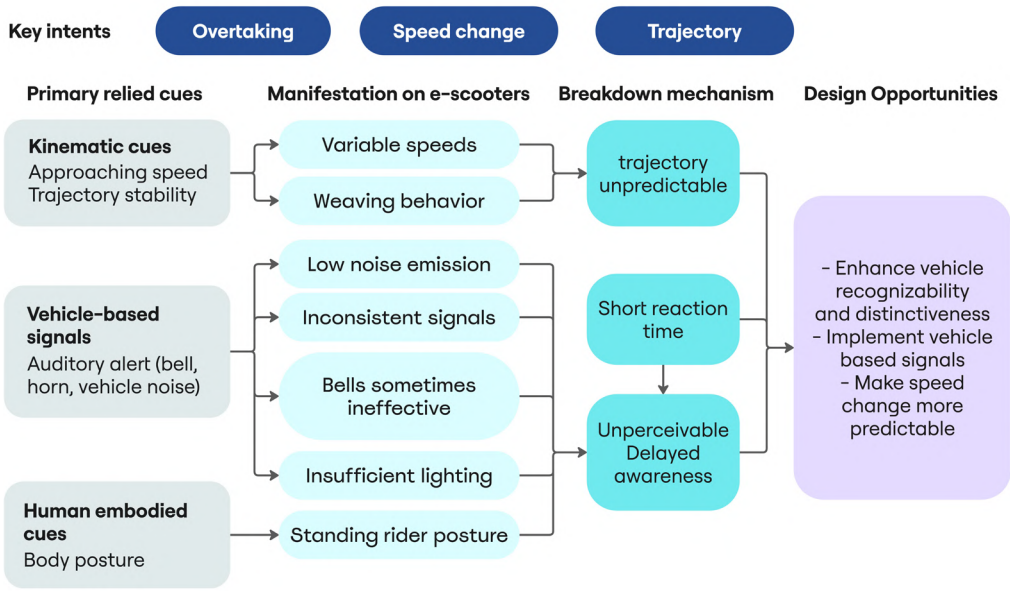


Figure 4.3: Mapping of e-scooter cues in shared spaces.

Scenario 2: Turning

Turning is treated as an individual scenario as it is a common maneuver occurring across various infrastructures, which specifically requires road users to communicate directional intent in advance. In motor traffic, this is achieved through indicators, while cyclists use arm signals. In contrast, for e-scooters, the lack of indicators and difficulty in performing arm signals limit the use of explicit signals, so other road users may tend to rely on implicit cues. Road users rely mainly on speed and head movements to anticipate a cyclist's future direction, but these cues are often ambiguous and insufficient for predicting turning intent before the maneuver is initiated (Westerhuis & De Waard, 2017). Lateral position on the road also affected judgments on cyclists' turning intentions (Petersen & DeLucia, 2026). Explicit signals are identified as the most reliable predictor of a turning maneuver (Petersen & DeLucia, 2026). These findings suggest that in the context of e-scooters, where movement patterns can be more variable, it may be even more difficult for other road users to correctly predict turning intentions.

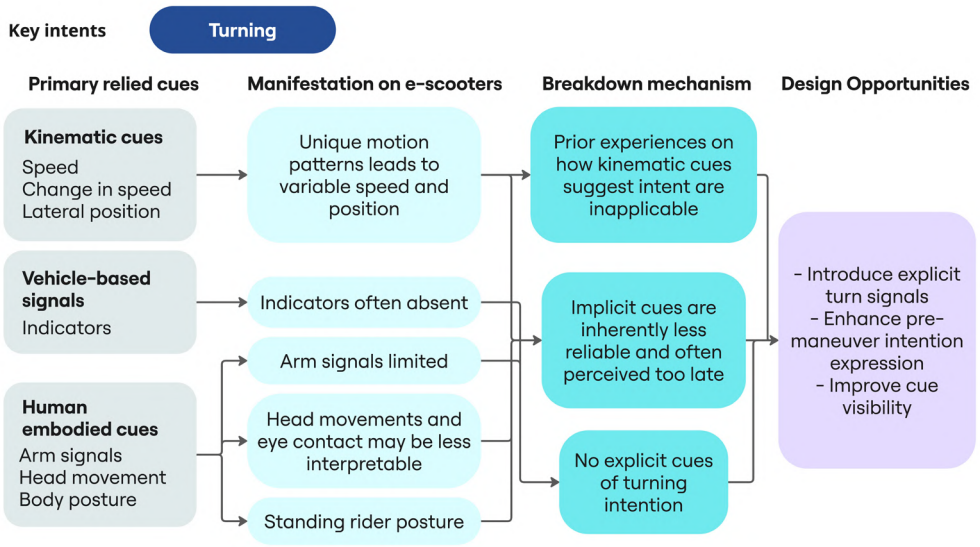


Figure 4.4: Mapping of e-scooter cues in turning scenarios.

Scenario 3: Unsignalized crossing encounters

In such scenarios, the trajectories of the e-scooter and another road user intersect - often perpendicularly - in the absence of formal traffic control, for instance, at uncontrolled intersections, or when a pedestrian crosses the road. These situations require road users to negotiate priority, and the exchange of cues typically happens more often.

For instance, in an interaction of e-scooter turning (Figure 4.5), negotiation is achieved through sequential and reciprocal exchange of behavioral cues, including deceleration, eye contact, and stopping (Tuncer & Brown, 2020). Similarly, in cyclist-driver interactions at uncontrolled intersections, cyclists were likely to use a mix of human-embodied cues, including head movement and hand gestures, and kinematic cues of speed change or stopping (Al-Taie et al., 2023).

Figure 4.5: An example of an unsignalized crossing encounter between an e-scooter and a pedestrian (shot from the e-scooter rider's perspective), where the e-scooter is moving on the cycle-lane, reaching a curve to the right, crossing trajectory with a pedestrian crossing the road. (Tuncer et al., 2020).

In the context of e-scooters, however, hand gestures would become less frequently used, while speed and trajectory changes may appear less predictable due to their high maneuverability, further reducing the clarity of intention during crossing interactions. Head movements and eye contact are assumed to remain present, but their visibility and interpretability may be reduced due to the compact size of e-scooters and the short interaction time. In addition, such human embodied cues are often absent in certain situations, for instance, at nighttime (Schieben et al., 2018).

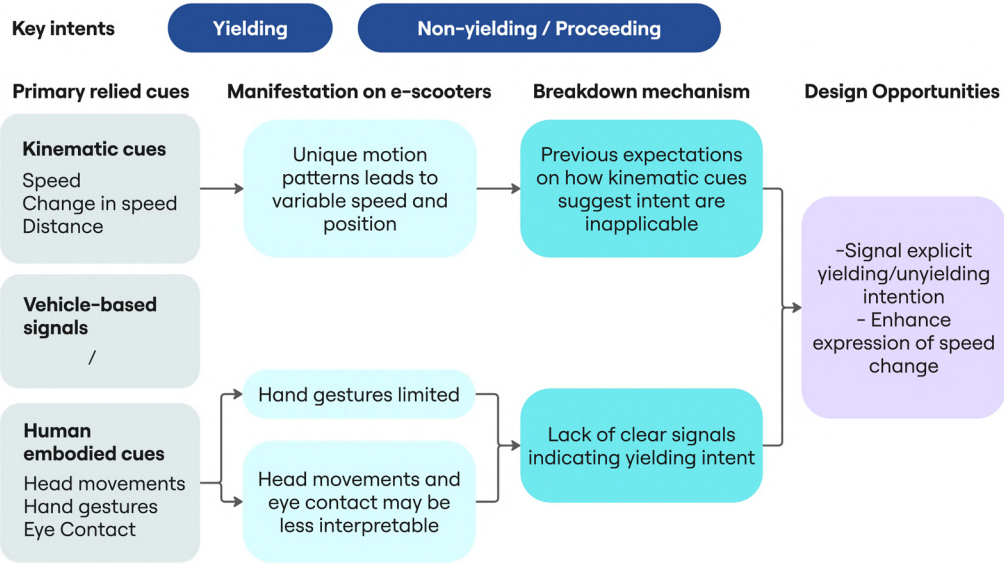


Figure 4.6: Mapping of e-scooter cues during unsignalized crossing encounters.

Scenario 4: Lane switching and merging

E-scooters are often observed to switch between lanes freely, which involves communicating directional change and negotiating priority with the RUs in the target road space.

Cars use indicators to signal merging intent explicitly, which is absent in MMVs. In situations where a cyclist needs to merge into a motor lane, speed-related cues are frequently observed, including acceleration, deceleration, or a complete stop, depending on the specific interaction context (Al-Taie et al., 2023). Head movement towards the driver and hand gestures are also commonly used cues.

While there is no focused study on specific cues that e-scooter riders use in these situations, given their flexible movement patterns and frequent lane switching behaviors, a lack of effective expression of intent is likely to make such maneuvers unpredictable for both road users in the same lane with them and the target lane of merging.

Figure 4.7: An e-scooter rider (right) intending to leave the current lane. Source: https://www.pinterest.com/bri0110/pittsburgh-penguins/

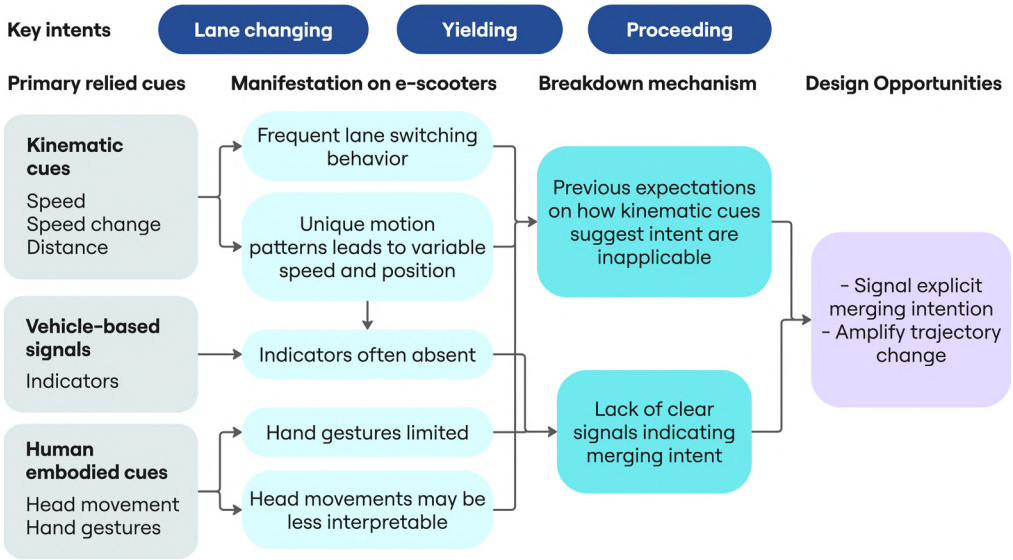


Figure 4.8: Mapping of e-scooter cues during lane switching and merging.

4.3 Design Implications

4.3.1 Summary of important intent and cues

Across the critical scenarios, key intents and the cues through which these intents are perceived are categrorized as follows:

Table 2: Important intents in the critical e-scooter interaction scenarios.

Motion intent		Social intent
speed change	trajectory change	priority negotiation
- acceleration - deceleration - stopping	- turning - lane exit - lane merging	- yielding - proceeding (non-yielding) - overtaking

Table 3: Important cues through which the above intents are perceived in the critical e-scooter interaction scenarios.

Kinematic		Human-embodied
speed-related	trajectory-related	- head movement - eye contact
- acceleration - deceleration - stopping	- directional change - lateral shift	

Motion intent refers to the vehicle's physical upcoming behaviors that are not directly in relation to another road user, but may potentially affect them due to space-sharing or future encounters.
Since these behaviors are directly expressed through vehicle movement, the corresponding kinematic cues often overlap with the intent itself. In the context of e-scooters, the main challenge concerning motion intents is that they are not perceived clearly or early enough, and a lack of explicit signals, with their flexible and variable movement patterns further reducing predictability.

Social intent refers to intents that are directly in relation to another RU, which mainly concerns priority negotiation. In current traffic, there are no explicit cues for such intents, and therefore they have to be inferred from a combination of kinematic and human-embodied cues. Their breakdown is commonly due to the cues not being perceived clearly or early enough, and how the cues correspond to intent is inherently ambiguous.

4.3.2 Design directions for dynamic signals

Indicating the upcoming speed and trajectory change prior to the actual maneuver emerges as an opportunity to inform interacting RUs about their upcoming behavior. This could be achieved by translating speed change and directional change into clearer vehicle-based expressions. For intents where standardized signals are already used, it is essential to incorporate them. In terms of social intents, some situations revealed that it would be beneficial if they could be expressed explicitly, indicating that additional expressions could be added as a reinforcement. While eye contact and head movements of the rider are difficult to be directly supported by the vehicle embodiment, they may be compensated for by alternative design features that express similar social cues.

This suggests two design directions for further exploration:

1) Amplify and enable early expression of speed and trajectory cues to clarify motion intent;
2) Add reinforcement expressions for social intent where existing implicit cues are insufficient.

4.3.3 Design directions for physical form

The mapping analysis revealed several form-related design opportunities. Although form alone does not communicate specific intentions, it can address the challenges by influencing how the vehicle is perceived before and during an interaction.

First, **acknowledging the presence recognizing the e-scooter** emerged as key interaction needs. This suggests that the vehicle should be easily noticed and clearly recognized as a vehicle, especially in shared spaces, where it may be mistaken as pedestrians. A distinctive appearance can enable early detection and recognition of the vehicle, allowing more reaction time during interactions. Furthermore, the appearance of the vehicle may also influence how its future behavior is anticipated. Due to their relatively recent introduction, there is an absence of common knowledge of perceiving and understanding e-scooters' motion and, thereby, predicting their next actions. This unfamiliarity often leads to uncertainties, while inexperienced RUs tend to perceive them as unstable and out of control.

Therefore, form should primarily carry three types of functions:
1) Support vehicle detection and recognition by establishing a distinctive and recognizable vehicle identity.
2) Establish appropriate behavioral expectations of the vehicle.
3) Support the dynamic communication cues by providing an appropriate base for their integration and expression.

At the same time, the redesign should preserve the essential qualities of an e-scooter to the best, namely, lightweight, compactness, and flexibility.

4.3.4 Interaction sequence

Synthesizing the findings in this section, communication during interactions can be understood as a sequence of information needs (Figure 4.9). Before any intent interpretations, RUs must first acknowledge its presence and recognize what type of RU the e-scooter is. Then they observe its current movement, which will be used as cues to interpret their social intent if encountering a direct interaction, together with other human-embodied cues. In parallel, based on the vehicle appearance and their experience, they form the expectations of behavioral characterestics of the vehicle, which influences how its motion and social intent is perceived.

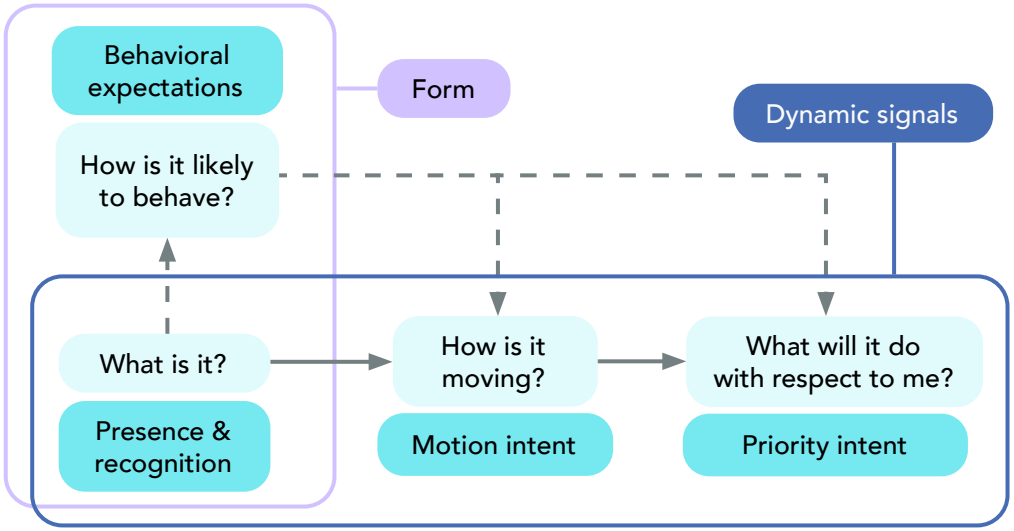


Figure 4.9: Sequence of information perception in traffic interactions.

This clarifies the roles of two complementary design aspects defined in the project:
1) vehicle form: supports vehicle recognition and shapes behavioral expectations
2) dynamic signals: support the communication of motion and priority intents while also improving vehicle recognition.

Consequently, the subsequent research explored these two aspects separately.

4.4 Design Principles

The key insights from the previous analysis are synthesized into the following design principles:

1 Strengthen vehicle recognizability
The vehicle should be readily identified as a vehicle rather than a pedestrian and remain easy to notice, particularly in shared spaces.

2 Express key intents through perceptual cues
Key intentions, such as turning, yielding, and merging, should be communicated primarily by strengthening the perceptual cues that road users already rely on to infer vehicle behavior.

3 Support quick intent interpretation
Communication cues should be intuitive, salient, and appear sufficiently early to provide other road users sufficient time to interpret and react.

4 Convey predictable behavioral characteristics through form
The physical vehicle form should improve predictability through establishing appropriate behavioral expectations of the vehicle.

5 Integrate dynamic cues into the vehicle form
The vehicle form should support the physical and visual integration of dynamic communication elements, allowing them to be embodied in the vehicle rather than as additional components.

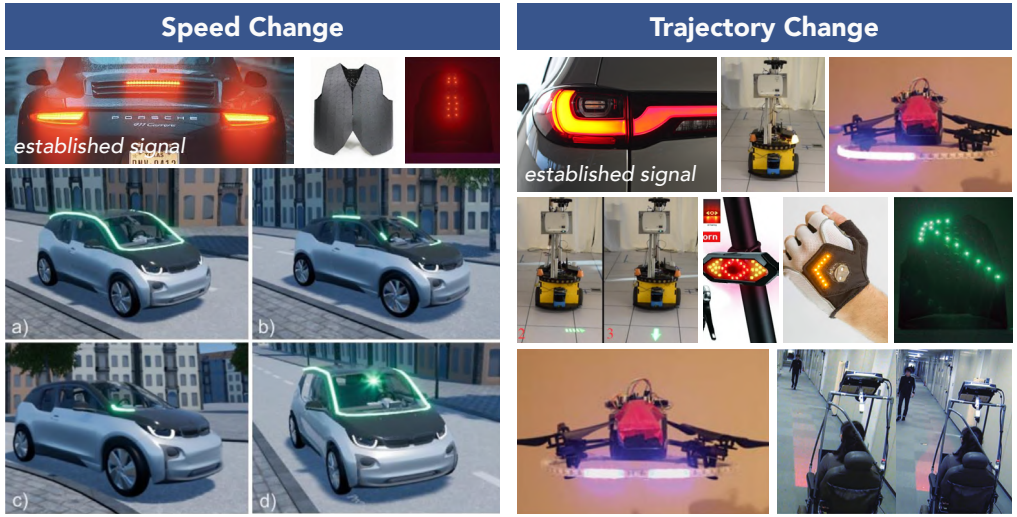
5 Intent Signaling

To identify relevant approaches and find inspiration for design strategies for intent communication, precedent research was conducted across multiple fields, mainly including robotics, external human-machine interfaces (eHMIs) in autonomous vehicles, other traffic signaling products, and biological strategies. The representative strategies, findings, and potential modalities are synthesized to inform further design directions.

5.1 Precedent Research

5.1.1 Motion intent

Across approaches and domains, the core principles of signaling speed change and trajectory are consistent, featuring direct and intuitive visualizations.



- red rear light = brake light
- pulsing or flowing light patterns: animation speed correlates with vehicle speed or speed change

- conventional turn-signal-like indicators
- arrows
- metaphorical cues (e.g. gaze direction)
- projected paths

Figure 5.1. Design precedents and summarized strategies of signaling speed and trajectory change.

5.1.2 Priority negotiation

While a wide range of design options and modalities of eHMIs have been studied, to maintain a focused scope of the current precedent research, different eHMI design approaches were first evaluated (Appendix 2). Based on this comparison, the precedent research focused on simple graphical designs and abstract light patterns, as they were considered the most suitable for the objectives of this project.

Many eHMI studies investigated how color influences pedestrian interpretation of vehicular intent. Aligned with conventional light semantics, red is typically interpreted as stopping while green signals permission to proceed (e.g. Oudshoorn et al., 2021; Xiao et al., 2026). This suggest that established associations can support intent interpretation.

Figure 5.2: Light bar eHMI used in the study by Oudshoorn et al. (2021).

Alternatively, some studies explored the shape, movement direction, and animation pattern of light-based eHMIs. For example, Xiao et al. (2026) explored conveying yielding intentions through a sweeping light pattern from the center toward both ends of the lighting area and a rhythmic blinking pattern. The study suggests that **a faster animation speed is more likely to be interpreted as unwillingness to yield**.

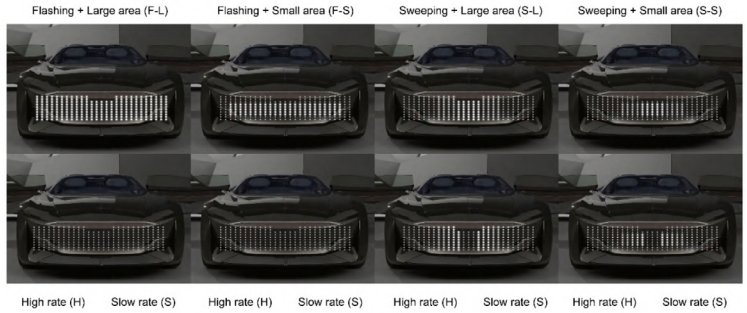


Figure 5.3: eHMI light patterns for communicating negotiation-related intentions (Xiao et al., 2026).

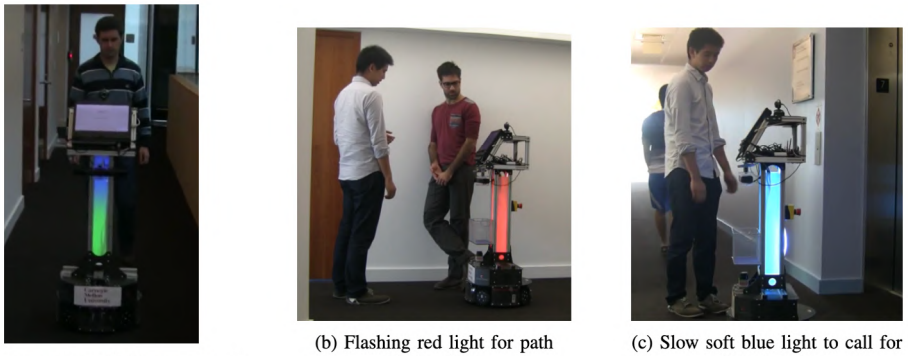
However, existing research does not yet provide a universally intuitive or consistently interpretable solution for communicating yielding intentions explicitly through abstract visual patterns.

5.1.3 States or affective meanings

Beyond explicit priority intent signaling, how light behavior, color, and movement qualities can communicate internal states, emotions, or social attitudes has been widely explored as well. Although these intents and expressions do not directly correspond to the intents in e-scooter interactions of yielding or proceeding, they can be adopted as inspiration for affecting how the vehicle's behaviors are socially perceived.

Figure 5.4: Two modes of the same robot in the study by Song & Yamada (2018), which were interpreted with friendly actions (left) and hostile actions (right).

Robotic interaction research studied how combinations of color, light patterns, and movement can express affective states. For instance, colors combined with light patterns can signal a robot's internal state, or be interpreted as different intentions (e.g., Baraka et al., 2016; Song & Yamada, 2018).



(a) Green progress light on an escort task

(b) Flashing red light for path obstructions

(c) Slow soft blue light to call for human help

Figure 5.5: Three light patterns with different color and animation to signal the internal states of a service robot (Jung et al., 2013).

Additionally, although some studies have explored communicating emotions using light patterns of different color and animation, such associations are known to vary greatly across individuals and cultures (Barchard et al., 2014; Feldmaier et al., 2016). Therefore, the project does not rely on general color semantics, but only those within the traffic context.

Interestingly, the colors green and red were found to carry similar semantic associations in robotics research. Green is commonly associated with positive states or friendly actions, while red often conveys negative meanings like warning, malfunctioning, or hostile actions. These converging findings indicate that green and red can potentially be used to reinforce the intended meaning in the intent signals, particularly concerning priority intents.

In soft robotics research, many studies explored how the body movement of a shape can convey various social or affective meanings, which suggests that rich expressivity can be achieved by performing basic movements of a simple form (Jung et al., 2013; Koike et al., 2024).

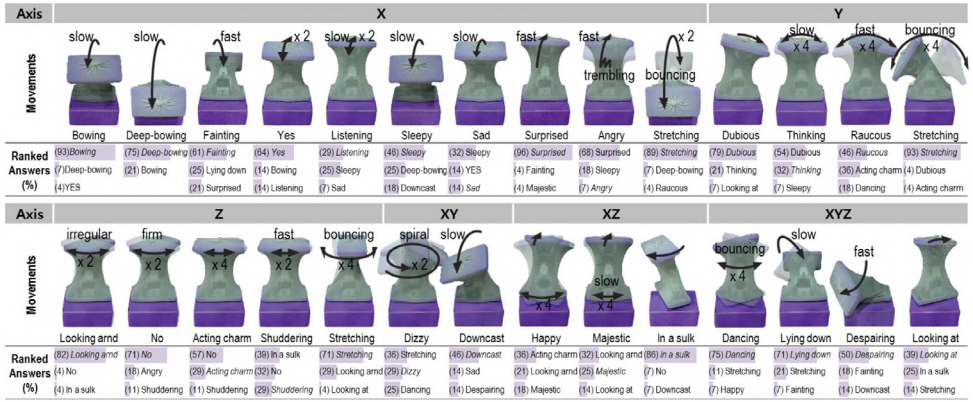


Figure 5.6: Movements explored and their ranks of recognition (Jung et al., 2013).

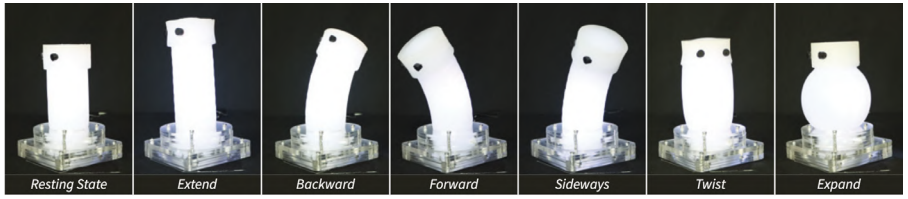


Figure 5.7: Motions of a robot with soft pneumatic actuators (Koike et al., 2024)

Across studies, movements are created by changing three main parameters: 1) direction, 2) expansion/contraction, 3) rotation.

5.1.4 Biological strategies

Biological threat display behaviors and deimatic behaviors were studied to explore intuitive and novel strategies for social intent expression.

Threat display postures

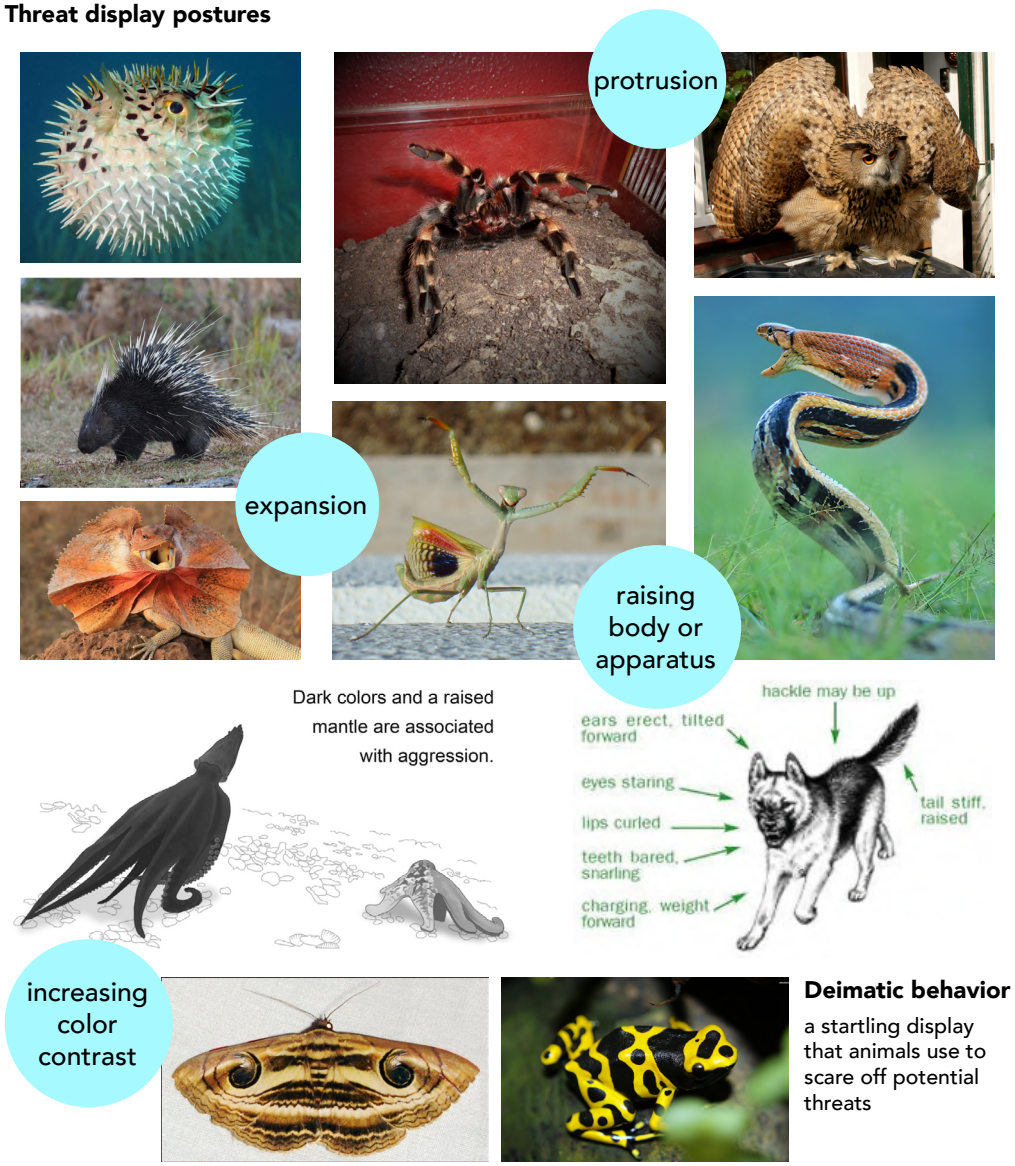


Figure 5.8: Collection of animal threat display postures and deimatic behavior.

Submission postures

Figure 5.9: Animal submission postures.

Threat displays are often associated with the **expansion** and **upward motion** of the body or apparatus, or with enhancing distinctiveness through **pattern or color contrast**, emphasizing the creature's visual presence. In contrast, to reduce visual threat, animals lower their body or lean backwards, presenting a **contraction** or **downward motion**.

In particular, **countershading** is a camouflage pattern found across different species where an animal's body is darker on top and lighter on the bottom. This gradient of color compensates for the way natural light falls on a three-dimensional body, reducing its visibility through lower color contrast (Scienceinsights, 2026).

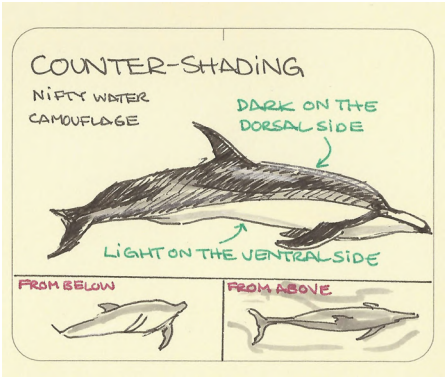


Figure 5.10: Illustration of the mechanism of countershading. Source: https://sketchplanations.com/counter-shading

Figure 5.11: Examples of countershading in nature. Source: https://www.instagram.com/p/Cn7yAttO3Qh/

5.1.5 The VAD Model

Many of the visual cues discussed in the above sections, especially movement patterns, do not communicate specific intents directly. Instead, they elicit affective meanings and influence how observers perceive the social attitude of the object. To apply the associated meanings for priority intent expression, this project adopts the three-dimensional Valence–Arousal–Dominance (VAD) model as a framework.

The VAD model (Russell & Mehrabian, 1977) is widely used to describe how visual and dynamic features are interpreted in terms of affective qualities. For instance, Tan et al. (2016) used the VAD model to identify what movement parameters contribute to which dimension, and can therefore be used to express emotion in a shape-changing interface.

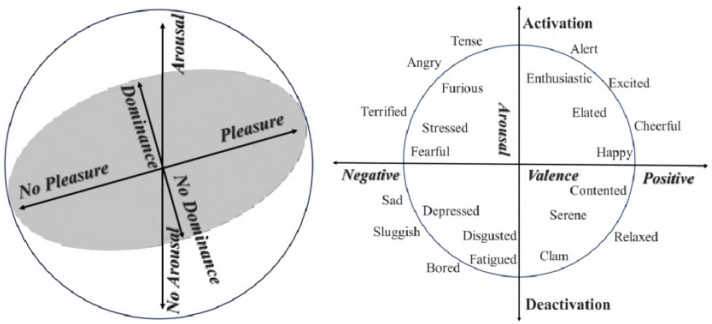


Figure 5.12: The VAD model.

In this project, the VAD model is used to describe how visual cues produced by the vehicle may influence road users' expectations during interactions, and the three dimensions are defined as follows in a traffic context:

• **Dominance**: The degree to which the vehicle tends to take priority and control over the road space, indicating how likely it is to yield when encountering other RUs.
• **Arousal**: the intensity with which the vehicle expresses its character or intent.
• **Valence**: The perceived friendliness or cooperativeness of the vehicle's behavior.

The project will primarily focus on the dominance level, as it directly relates to perceived yielding behavior during priority negotiation.

Therefore, using the VAD model as an interpretive framework on the above research, recurring relationships can be found between parameters and perceived dominance level. The study by Tan et al. (2016) discovered that an upward direction speed indicates high dominance, while a downward direction indicates low dominance, and that moving speed positively correlates with dominance. Animal threat display behaviors can also be regarded as an act to increase the perceived dominance level, while countershading is a feature that lowers the dominance level. This framework can further help to identify how design features relate to dominance levels.

5.1.6 Design implications

Different strategies should be adopted to design signals for different types of intent:

- Speed and trajectory intent can be expressed in an intuitive way through light animation patterns and directional visualization, and adopt conventional signals.
- Priority negotiation expression should combine the perceptual cues that are associated with perceived high and low dominance.

Perceptual features that are found to be associated with dominance level are summarized as below:

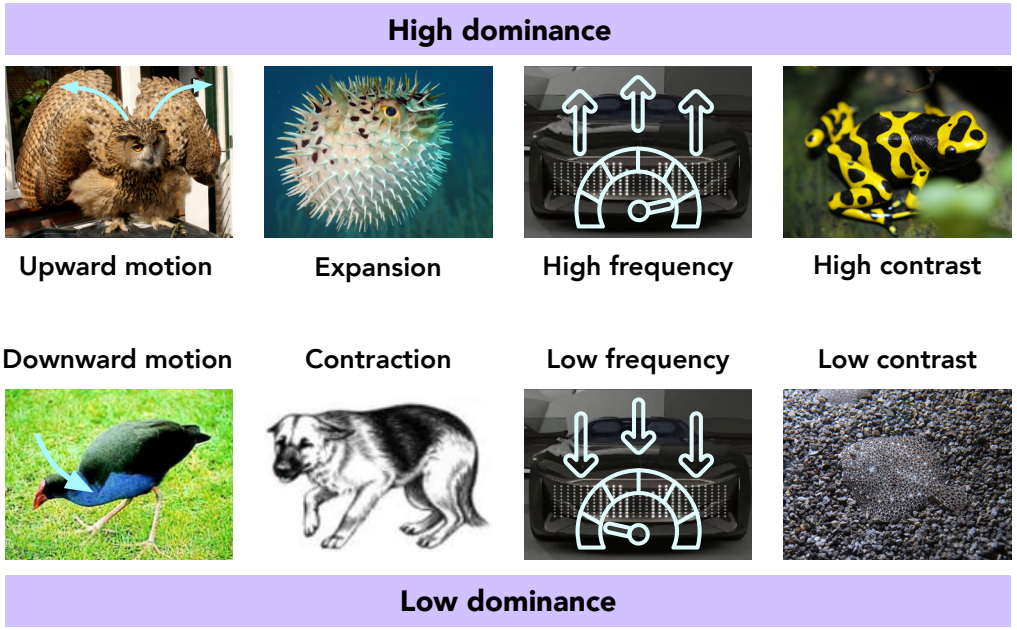


Figure 5.13: Summary of perceptual fearures of low dominance and high dominance.

5.2 Communication Modalities

The research in this section suggests various modalities for intent expression. To identify the suitability for this project, the strengths and limitations of each modalities are evaluated regarding the objectives of this project.

Table 4: Analysis of the strengths and limitations of the main modalities in the context of this project.

	Strengths	Limitations
Light (LED)	• Widely researched and applied in intent • communication Has established associations and meanings, especially in traffic context • Enables high expressivity with simple animation • Suitable for embodiment	• May have a limited number of possible meanings to be communicated • May require learning for clear interpretation
Ground projection	• Effective in conveying spatial information • Can extend the display outside the vehicle body • Less prone to vertical occlusion	• High hardware requirement • Relatively high energy consumption • Limited readability in complex scenarios Sensitive to lighting conditions
Motion	• Highly embodied • Align with mental models • Efficient in conveying affective meanings	• Often performed by the whole body, which is difficult to translate into e-scooters

LED lights emerge as the strongest candidate in terms of both expressivity and practicality, and were selected as the primary modality. Projection is kept as a secondary or reinforcing channel. How simple motions can elicit rich affective experiences opens up a broad design space and introduces potential associations with natural animal behaviors. However, while suggesting a novel direction, the meanings expressed through motion typically rely on performing the movement through the object's body, indicating that it has to be translated into vehicle-based expressions through alternative approaches.

6 Form

This chapter investigates how vehicle form can support intent legibility during interactions. In this project, ***form*** is used to refer to design aspects relevant to the vehicle's visual appearance, including its overall styling, vehicle-specific elements, and formal language.
Among the three identified functions of form, vehicle recognizability is considered a prerequisite for intent interpretation, and is primarily achieved by establishing a distinctive and recognizable vehicle identity, supported by lighting elements. Since the corresponding design strategies are relatively straightforward, this chapter primarily researches how form influences the perception and interpretation of vehicle behavior, corresponding to the legibility of specific motion and priority intent. It first defines the perceptual layers through which form influences intent interpretation, and then investigates the visual features that contribute to each layer through visual analysis and precedent research.

6.1 Form and Intent Perception

Vehicle form influences how RUs perceive and interpret its behaviors before and during interactions. The appearance of a vehicle shapes expectations about its behavior (Dey et al., 2017; Klatt et al. 2016). Vehicle type helps traffic participants to determine its general motion characteristics and driving style (Schieben et al., 2018), and thereby affects how its movement is perceived. For example, due to its size, a truck is associated with being slower and more dangerous to collide with than a sports car (Färber 2016, as cited in Schieben et al., 2018). Over time, people develop associations between certain vehicle features and expected movement characteristics. When a new vehicle type emerges, such as e-scooters, due to unfamiliarity, thre is a lack of knowledge in perceiving and understanding their motion and, consequently, predicting what they can or might do next. As a result, people tend to apply the previously formed associations to anticipate how it might behave in traffic. This indicates that in designing the e-scooter form, perceived characteristics should align with actual vehicle behavior to ensure correct expectations.

Beyond expectations, the vehicle-based features can affect how its current behavioral state is perceived, for instance, how legible its moving direction and speed change are. This forms the basis for understanding the vehicle's current motion and anticipating its upcoming actions.

While the above aspects are determined by vehicle-based features, design features – including formal language and affective qualities – shape expectation in another layer, by playing a role in affecting the car's perceived character, for instance, aggression or assertiveness, or, conversely, its cuteness or friendliness (Dey et al., 2017). Vehicle appearance is also associated with stereotypes about the kind of people who own them, and their driving behavior (Garham, 2009, as cited in Dey et al., 2017; Garham and Darshana, 2005, as cited in Dey et al., 2017). Although these associations do not directly communicate specific intents, they influence how the vehicle and its behavior are socially interpreted.

Therefore, form should contribute to intent legibility through the following 3 layers:

Movement expectation	Concerns about what kind of **motion characteristics** people anticipate the vehicle to exhibit in general.
State readability	Concerns about how effectively the **current movement and behavioral state** of the vehicle can be perceived, which supports the prediction of subsequent movements.
Character	Concerns the baseline character created by the design features that the vehicle conveys, including its **driving style, interaction attitude, and personality**, which influences how its behaviors are socially interpreted.

Note that the three perceptual layers are divided to distinguish the primary design aspects that contributes to the perceptual features of layer. Rather than being independent from each other, they are interrelated and may overlap in practice.

The following sections investigate which features contribute to each of these perceptual layers.

6.2 Vehicle-based Features

Vehicle-based features - involving vehicle specific components, posture, and porportions - primarily influence intent through the movement expectation layer and state readability layer. The following behavioral characteristics were selected under each layer based on their relevance to intent prediction:

Movement Expectation layer

Speed how fast the vehicle appears to be.

Maneuverability how easy it appears to be for the vehicle to change direction, which indicates the likelihood of turning suddenly, and affects how stable and under control the vehicle looks.

State Readability layer

Directionality how clearly the vehicle's moving direction can be perceived.

Speed legibility how easily the current speed and speed change of the vehicle can be perceived.

A visual analysis on several common MMV types (Table 5) was conducted to examine how vehicle-based features contribute to the perception of each behavioral characteristic (See complete table in Appendix 3).

Building on this analysis, Table 6 presents the main features that are associated with increasing and decreasing each characteristic, and further extracted higher-level perceptual features, which can act as design guidelines in later stages of form development.

Table 5: Analyzed MMV type and corresponding behavioral characteristics.

	Bicycle	Fat-bike	Moped scooter	Mobility scooter	E-scooter	Segway	Skateboard
Speed	medium	medium-high	high	low	medium-low	medium-low	medium-low
Maneuverability	medium	medium-high	medium	low	high	high	high
Directionality	high	high	high	high	medium-low	low	low
Speed legibility	high	medium	medium-low	high	low	low	medium-high

Table 6: Main vehicle-based features and perceptual features associated with each characteristic.

	+	-	Perceptual Features
Speed	• Larger wheels • Electric assistance • Leaning posture • Motorized vehicle association	• Smaller wheels • Manually powered • Standing posture	• Visible movement of propulsion • Archetype association
Maneuverability	• Smaller wheels • Thinner wheels • Slim profile and base • Smaller size • Upright posture	• Larger wheels • Wider wheels • Large base • Larger size • Sitting posture	• Slim profile • Minimum longitudinal geometry • Small ground contact area • Low visual center of gravity
Directionality	• Inline wheel configuration • Clear front • Elongated body	• Side-by-side wheel configuration • No clear front/back distinction • Upright posture	• Longitudinal geometry • Clear, distinguishable front
Speed legibility	• Visible wheel motion • Visible rider action	• Low wheel motion visibility • Low rider action visibility	• Motion visibility • Large vehicle size

Design Implications

At the ***Movement expectation layer***, misalignment in expected and actual e-scooter behaviors mainly occurs in speed expectation and the feeling of stability and control. High speed is often associated with a leaning forward posture, larger wheels, or large vehicle size, all of which are absent in e-scooters, which may cause people to mistakenly assume they are slow. At the same time, features including a slim profile, upright posture, small inline wheels, and a narrow base visually communicate its high maneuverability and movement flexibility. This is consistent with exhibited e-scooter behavior, further confirming the need for clearer intent cues. This may also explain why non-e-scooter users may perceive e-scooters as unstable and out of control (Šucha et al., 2023).

On the ***State readability layer***, the upright posture reduces perception of directionality, which is further exacerbated by a lack of a clear vehicle front, making it difficult to anticipate its trajectory. Compared to other MMV types, visual indicators such as wheel movement or rider body motion are less visually pronounced, making speed changes more difficult to perceive.

Drawing from the above insights, several adjustments to vehicle-specific features may help improve behavioral predictability while preserving the essential characteristics of an e-scooter. These include:

- **Making the vehicle's front clearly distinguishable**
- **Increasing the visual mass of the base**
- **Moderately increasing wheel size and width**

However, since these adjustments need to be made within the inherent configuration and maneuverability of e-scooters, their influence on perceived behavioral characteristics is expected to remain limited. Therefore, the integration of dynamic cues is still necessary.

6.3 Precedent Research

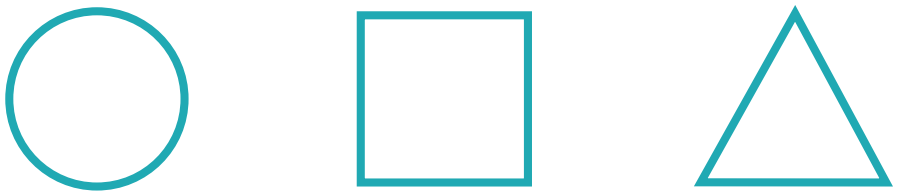
Precedent research focuses on the ***Character layer***, investigating how different kinds of design features influences the perceived affective qualities.

6.3.1 Shape language in design

Many studies have explored how the shape language in products can be associated with affective meanings or even personalities. A recurring pattern across studies is that round, contoured objects are associated with qualities such as safeness, agreeableness, positive conscientiousness, and harmony (Kapkın & Joines, 2018; Sunstrum et al., 2024). In contrary, sharp and angular objects are perceived as more aggressive and colder, and may even elicit fear, but can be more interesting and thought-provoking to look at (Lidwell et al., 2010; Kapkın & Joines, 2018). Additionally, tall, square shapes were perceived as regular, prototypical, and familiar, which may be ideal for products that aim to convey a traditional, conventional, and reliable image (Sunstrum et al., 2024).

Similar strategies have also been applied to the design of cartoon characters, where circles are used to create friendliness and warmth, squares are often used to create strong, reliable figures or give a sense of weight and how grounded or balanced a character or an object is, and triangular shapes are often used for heighten fear and menace in a character is, or sometimes to allude to their strength (The Walt Disney Family Museum, 2020).

These general patterns are also reflected in product-specific features.



Soft, squishy	Solid, sturdy, strong	Sharp, directional
Harmless	Supportive	Dynamic
Approachable	Reliable	Dangerous
Changeable	Inflexible	Unpredictable

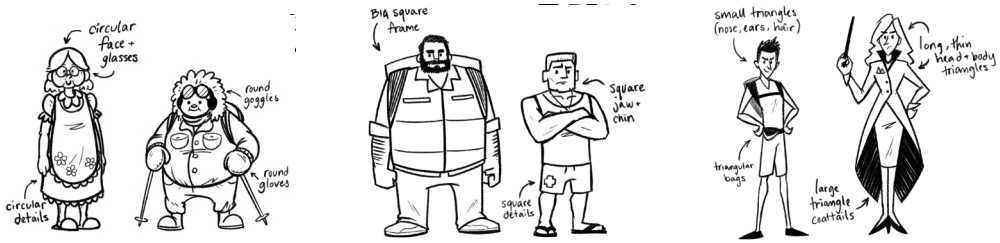


Figure 6.1: Affective meanings associated with simple shapes and application on characters. Adopted from Tips & Techniques: Shape Language, by The Walt Disney Family Museum, 2020.

6.3.2 Automotive styling

Automotive styling research suggests that visual appearance not only influences aesthetics, but also shapes expectations about a vehicle's behavioral characteristics. For example, Chen et al. (2007) investigated the effects of design features on the perception of automobile designs. Through a survey on the affective responses to the 24 automobile styling designs (Figure 6.2) using 11 bipolar adjective pairs, they discovered that different design features affect perceptual qualities differently. Of particular relevance to this project, perceptions of "Static – Dynamic" and "Weak – Strong" were influenced primarily by the existence of side vents and the shape of headlights, followed by the overall profile. These two pairs of features correspond to the two perceptual aspects identified in the project: **expected movement characteristics of the vehicle and its perceived character**.

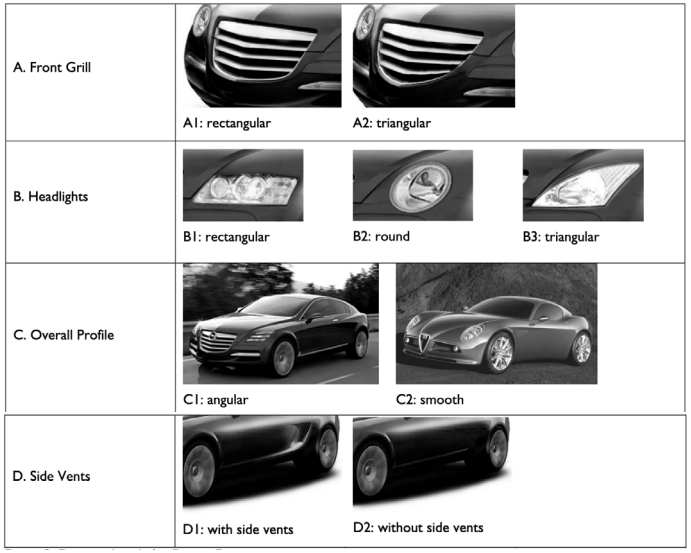


Figure 6.2: Discrete levels for design features (Chen et al., 2007).

Figure 6.3: The vehicle perceived as strongest and the most dynamic (left), and weakest/most static (right) (Chen et al., 2007).

In addition, automotive designs can elicit reactions similar to responses to human faces, where facial features – including structural elements as well as static facial expressions – may influence one's perception of another person's personality (Argyle, 2002, as cited in Windhager et al., 2008). Windhager et al. (2008) studied the link between perception and the geometry of a car front and its constituent parts. They identified that the rating of car fronts varies mainly along a single dimension identified as "power". Perceived maturity had the greatest contribution to this vector, followed by the interpersonal attitudes of dominance, arrogance, anger, and hostility, traits that are potentially relevant to the dominance level defined for this project (Section 5.1.5).

Cars with higher "power" tend to exhibit a horizontally elongated hood, a more pronounced lower front, and more angular headlights, features that resemble visual characteristics associated with mature and dominant human faces. Similarly, a study by Landwehr et al. (2011) found that participants rated car fronts with upturned grilles friendlier, and rated those with slanted headlights with a downturned grille more aggressive.

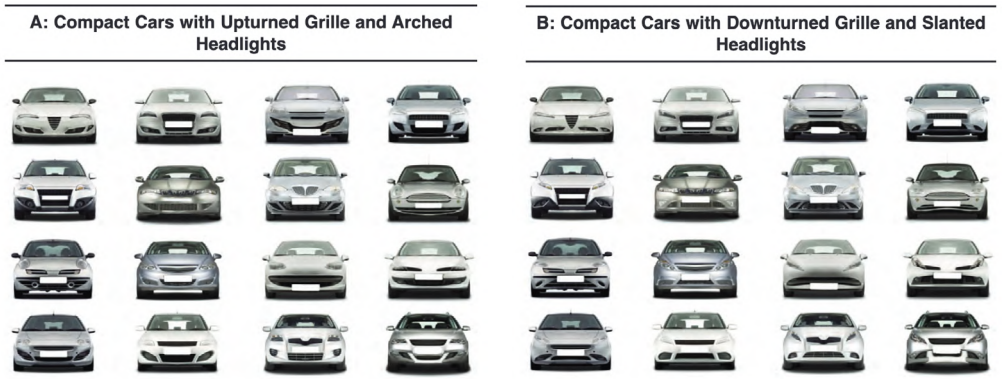


Figure 6.4: Comparison between cars with upturned grille and arched headlights, and cars with down turned grille and slanted headlights (Landwehr et al., 2011).

Taken together, the findings indicate that both the local design features, particularly the vehicle front, and overall form contribute to shaping behavioral expectations of the vehicle through the *movement characterics* and *character* layers.

6.3.3 Low and High Dominance Features in Products

To identify how specific design features affect the affective qualities of a product , a variety of products are collected, ranging from those that give a calm, peaceful, and approachable feeling (low dominance), in contrast with those with an assertive and even aggressive feeling (high dominance) (Figure 6.5). The extracted features are presented in Figure 6.6, which will inform the further form development.

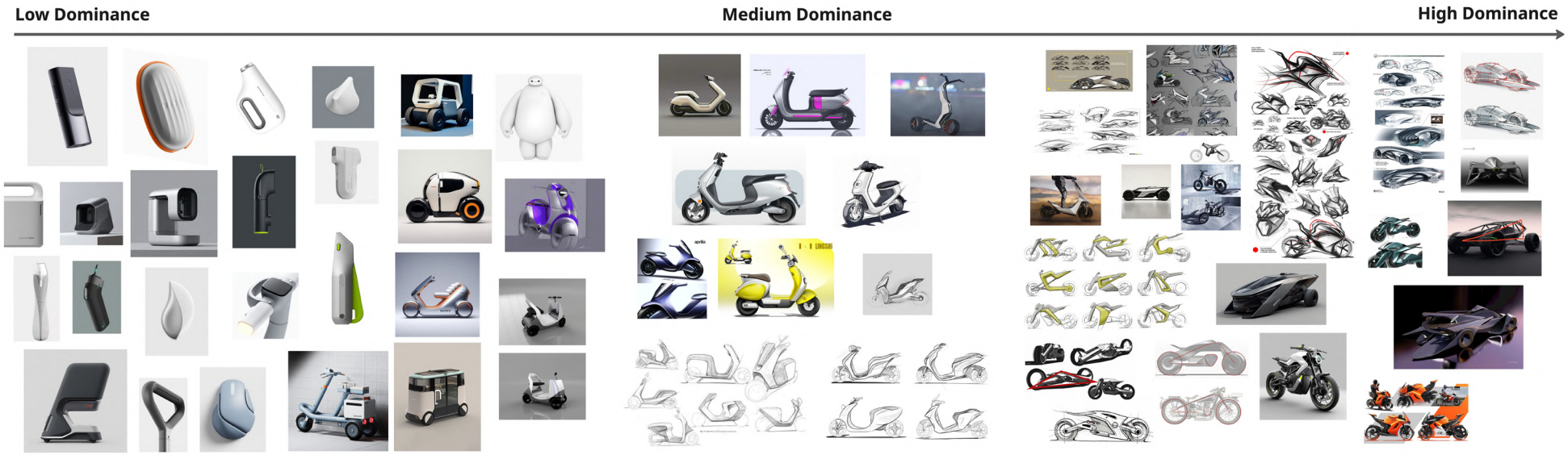


Figure 6.5: Collection of designs with perceived low to high dominance.

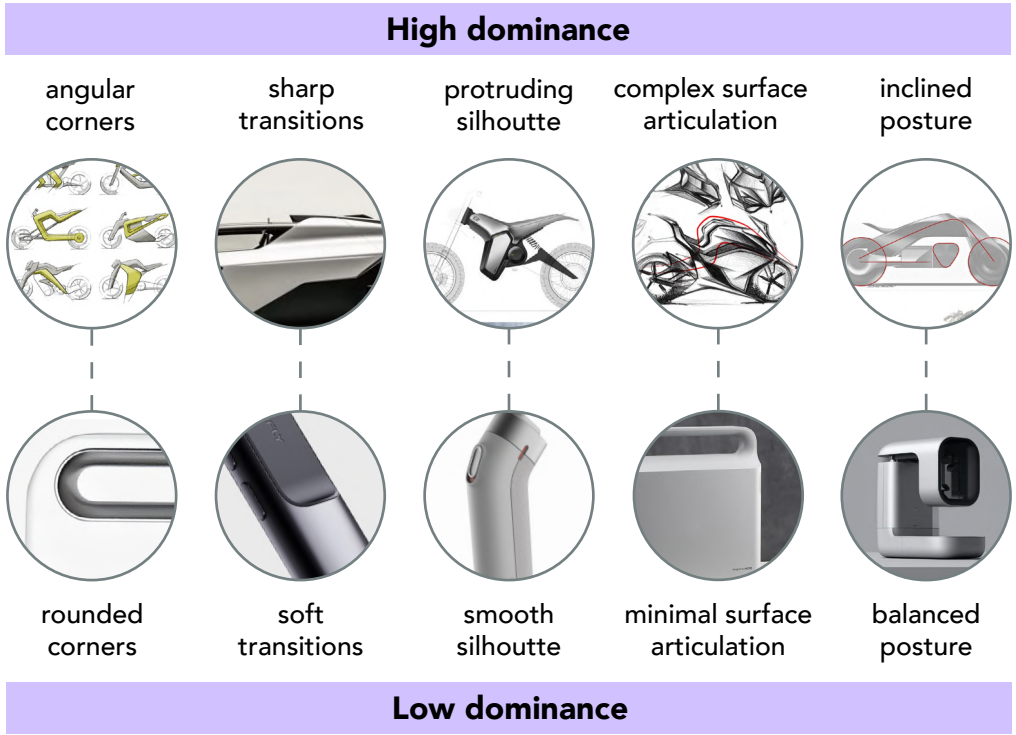


Figure 6.6: Key design features that contribute to the low and high dominance level in products.

Design Implications

Building on the analysis in Section 6.3, the perceived dominance level is expected to shape the behavioral expectations of a vehicle, including both its movement characteristics and character, and it can be influenced through adopting different visual features in the formal language.

Overall, **the identified relationships between visual features and perceptual qualities provide design guidelines for the subsequent form development**. Moreover, many visual features influence multiple perceptual layers simultaneously. For instance, the character layer naturally overlaps with movement expectations, as perceived driving style is associated with movement characteristics. Consequently, features intended to influence one perceptual layer are likely to affect the others. Form should therefore be considered holistically rather than optimizing each layer independently.

As dominance level can be associated with vehicle character, this suggests a potential design direction: changing the vehicle form to increase its perceived dominance level, therefore conveying a greater expectation that the vehicle will proceed rather than yield during interactions. Accordingly, the vehicle should transform from a baseline form to a "high-dominance form". The transformation strategy is explored in the following chapter.

The visual analysis also indicates that **the baseline form should convey a medium dominance level**. Although a low-dominance baseline might appear intuitive for promoting safe and cooperative interactions and distinguishing from a high-dominance version, the e-scooter is inherently a powered vehicle, which possesses great speed and maneuverability. Especially compared to pedestrians, who are more vulnerable road users, they have a greater potential to claim priority in shared spaces. Therefore, a medium dominance level more accurately represents its interaction potential while still allowing the transformed state to communicate an increased expectation of proceeding.

To clarify the primary considerations for subsequent form development, Figure 6.7 synthesizes the relationships between key design elements, the perceptual aspects they influence, and the corresponding functions they fulfil.

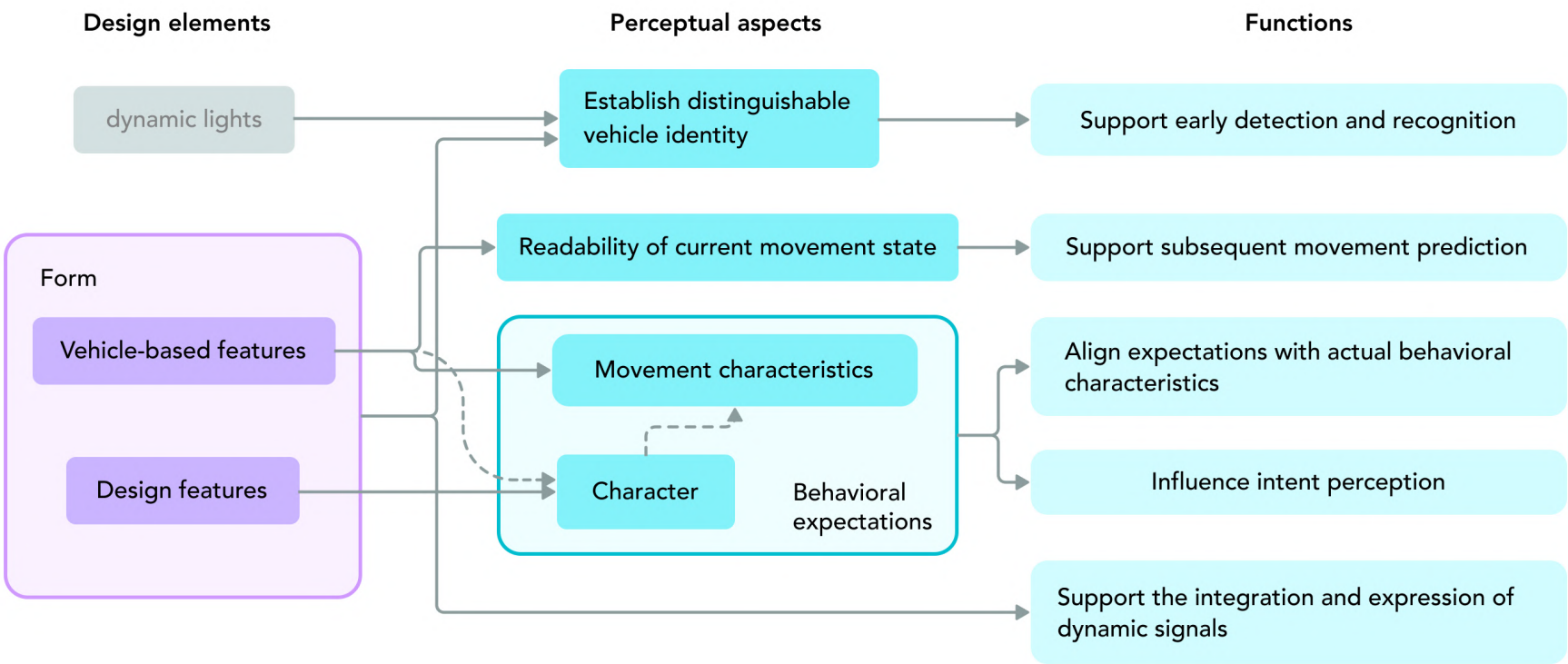


Figure 6.7: Relationship between key design elements in vehicle form design, perceptual aspects, and functions.

7 Form Transformation Strategy Exploration

This section explores potential strategies for form transformation. While physical transformation of the vehicle (e.g. through mechanical parts) were explored (Appendix 4), this direction was considered unsuitable regarding the production feasibility and safety for traffic application. Therefore, the explored approaches focus on light-induced effects. Two approaches were experimented and evaluated, informing the selection and adaptation of the transformation strategy.

7.1 Light-and-Shadow Effect on a 3D Surface

Mechanism

Several design works and studies (e.g., Pont, 2019; Wåseth et al., 2025) about the interplay between light and shape suggest that light and shadow effect can influence how an object looks. Similar strategies could be applied to create the form transformation, potentially using 3D surface geometries .

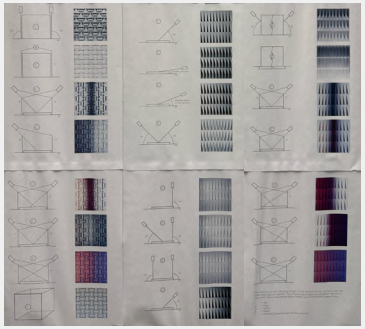


Figure 7.1. A research work based on the art by Jan Schoonhoven.

Explores how light settings that vary in type, number, direction, and color can change the appearance of the same art piece.

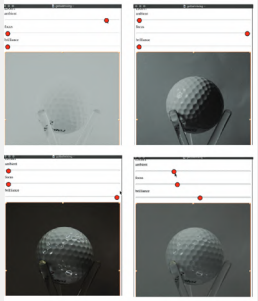


Figure 7.2. Varied appearance of a light probe illuminated with different light or weighted combinations (Pont, 2019).

The appearance and texture of an object changes with light settings.

Figure 7.3. Screenshots from a video that apply light from different directions on a face.

Light from different directions can change how pronounced facial features look.

Experimentation

Experiments were conducted by making simple geometries and shining light with LED lights or a flashlight from different directions to get a basic understanding of what effects can be created.

Figure 7.4: Initial exploration on the light-and-shadow effects on simple geometries.

Insights

- Under suitable conditions, applying light on a 3D geometry, can create evident shadows, significantly changing the appearance of the surface.
- An evident "shape changing" visual effect requires careful control of light direction, which is difficult to achieve in natural conditions.
- The effect also changes with the movement of the light source, demonstrating potential in combining dynamic light signals for motion intents.
- The lower ambient light intensity or the higher intensity light source is, the more evident the effect is.
- The effect is sensitive to ambient light conditions. In regular daytime conditions, sunlight is a constant downward light source, which need to be taken into consideration.
- The 3D geometery will still be visible under the baseline condition, suggesting that it requires balance between concealing the patterns and improving shadow visibility.

7.2 Layered Structure with Mirror Film

Mechanism

A one-way mirror film reflects about half the light that strikes its surface, while letting the other half go straight through. As a result, when viewing from the side with higher light intensity, it functions as a mirror, while you can see through from the opposite side (Figure 7.5).
This mechanism suggests that by creating a layered structure with a mirror film, changing the light intensity could potentially achieve the transformation effect by revealing hidden elements.

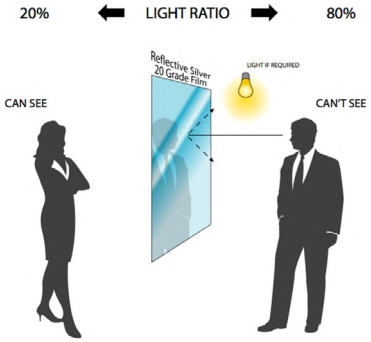


Figure 7.5: Illustration on the mechanism of one-way mirror films.

Experimentation

A series of experiments were conducted using this strategy (Figure 7.6), investigating its performance under different conditions (See the complete documentation in Appendix 5).

Insights

- The shape of the internal space directly defines the shape of the revealed pattern, making the effect more controllable.
- The patterns are completely invisible under the baseline condition, with the external surface being smooth and consistent, which aligns with the features of low-dominance forms.
- When the mirror film is only used on the patterns, the patterns are already visible before illumination, resulting in a less significant transformation effect compared to revealing internal patterns under a surface of mirror film.
- This approach is sensitive to ambient light conditions, and high-intensity LEDs with uniform surface illumination is required to achieve an evident effect under bright sunlight.

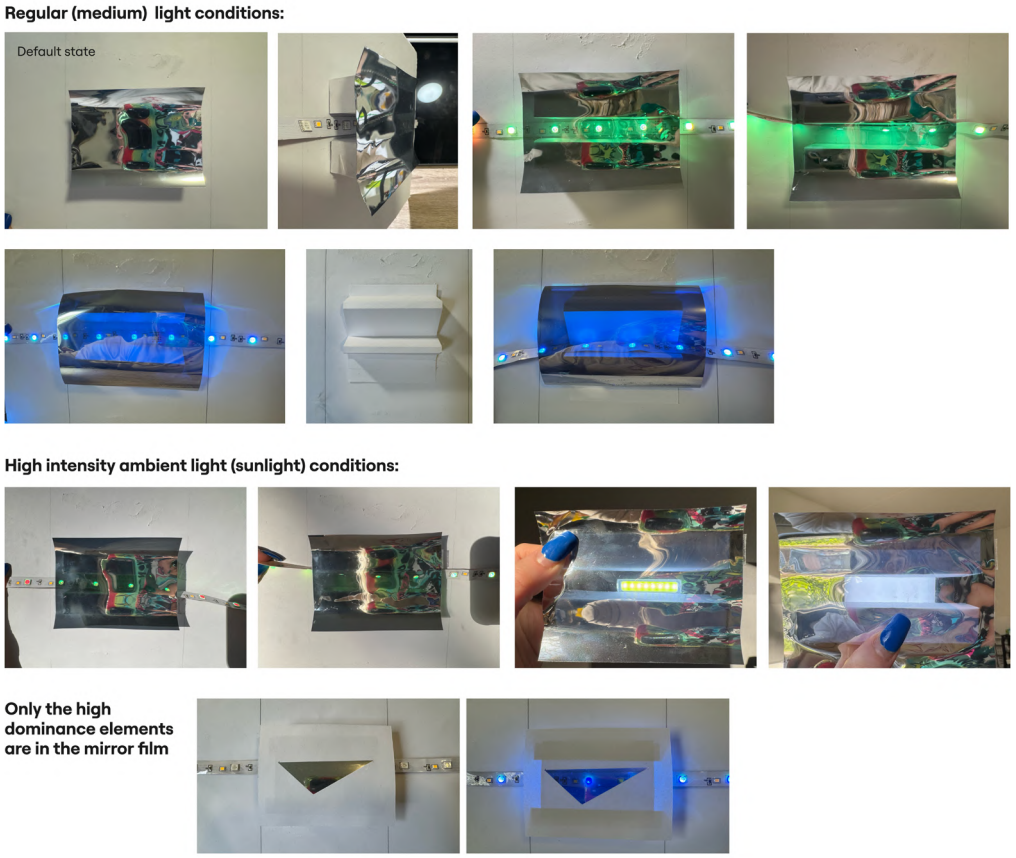


Figure 7.6: Experiments on a layered structure with mirror film.

7.3 Evaluation and Selection

While both strategies have strengths and limitations, the layered structure approach was considered less suitable. First, this transformation mechanism reveals the patterns in an internal space, which is perceived more as a spatial effect rather than a transformation of the vehicle's physical form. And the high-dominance form is often associated with protruding elements, while this approach looks more inward concave. In addition, to achieve the optimal transformation effect, the exterior of the vehicle will be a glossy, reflective surface. High reflectivity adds visual complexity to the base form, which doesn't align with low-dominance features. It may also create distractions for other RUs, creating potential safety risks. Furthermore, the transformation reveals the patterns primarily through a color change, while using 3D geometry can produce a richer transformation through both the contrast of light and shadow and color contrast. While both mechanisms are sensitive to ambient light conditions, the influence on the layered structure is considered stronger than on the 3D surface approach.

Therefore, **the 3D surface approach is selected as the form transformation strategy**.

8 Design Framework

8.1 Definition of Priority States

Chapters 5 and 6 explored how priority intent can be expressed through dynamic signals and vehicle form respectively. While research suggested that the appearance of a vehicle influences people's expectations of its behavior, the key factors that RUs rely on to make yielding or passing decisions are still kinematic cues like speed and distance (Dey et al., 2017), which indicates that form alone is insufficient in expressing priority intent. Conversely, as there are no widely recognized explicit signals for priority intent, light signals alone are likely to be insufficient either.

This suggests a strategy of conveying priority negotiation cues through two complementary channels: the vehicle's physical form as an implicit layer and light signals as an explicit layer.

Form

The two form states are defined as a *base form* with a medium dominance level and a *high dominance (HD) form*.

As discussed in Section 5.1.5, perceived dominance level refers to the degree to which the vehicle claims priority and control over the road space, indicating how likely it is to yield when encountering other road users. Rather than directly communicate specific interaction decisions, the form states shape expectations about the vehicle's behavioral characteristics, influencing how its movement and priority signals are interpreted. Table 7 analyzes the behavioral characteristics each form variation should convey, and the types of traffic behaviors that are likely to be expected. It further examines how these characteristics bias the interpretation of both motion and social intent in interaction.

The transformation between two form states is achieved through the light-and-shadow effects on the surface geometry created by the structural lights. Because the form state reflects the general behavioral characteristics and is not necessarily in relation to a specific interaction scenario, the transformation will be activated automatically when the vehicle exceeds a predefined speed or acceleration threshold, and return to the base forn when the activation conditions are no longer satisfied.

Table 7: Behavioral characteristics, expectations, and biases on intent of the defined two form variations.

	Base form	HD form
Dominance level	medium	high
Behavioral characteristics	Calm, cautious, controlled	Assertive, confident, strong
General traffic behaviors	• Smooth and stable movement • Low likelihood of abrupt changes • More adaptive behaviors	• More dynamic movement • May perform abrupt movements and more frequent weaving behaviors
Biases on **motion intent**	• Low to medium speed • No sudden speed changes • No sudden trajectory change	• Relatively high speed • Potential acceleration • May exhibit sudden or more frequent trajectory change
Biases on Social/ **priority intent**	Yielding expectations is likely to depend on the interaction context (e.g. relative vulnerability of the other road user) and inferred from other relevant cues	Tendency of non-yielding during priority negotiations Higher likelihood of overtake in shared spaces

Light signals

In addition to the implicit communication through form, dynamic light signals express explicit interaction decisions during priority negotiation situations. These *priority signals* include a **yielding signal**, indicating the rider's intention to give way, and a **proceeding signal**, indicating the intention to maintain priority. They are activated manually by the rider, as priority negotiation depends on the rider's personal judgment in a specific interaction scenario.

Although overtaking was identified as an individual intent during the scenario mapping, it will not be assigned with a dedicated signal. As yielding and proceeding

already require two newly introduced signals, adding a third signal would increase the difficulty in designing the cues and the complexity for interpretation. Moreover, in traffic conventions, overtaking is already communicated through motion- and presence-related cues such as turn signals in motor traffic and bells on bicycles. Therefore, it is considered sufficient that overtaking should be expressed through a combination of motion-related information and priority negotiation.

Combinations

Not all combinations of form state and priority signals are enabled. Although behavioral characteristics conveyed by the form and interaction decision expressed through the priority signal are conceptually independent, conflicting combinations may introduce ambiguity as both are conveyed through visual features. Therefore, the high-dominance form is only combined with the proceeding signal, while the base form can be combined with both priority signals.

	No signal	Yielding signal	Proceeding signal
Base form	State 1	State 2	State 3
HD form	State 4		State 5

Figure 8.1. Five priority states created by the valid combinations of form states and light signals.

8.2 Design Definition

The proposed design is an e-scooter with multi-layer communicative features integrated into its vehicle embodiment to improve its intent legibility through two complementary channels: physical form and dynamic signals.

The vehicle form improves vehicle detectability and recognizability, enhances readability of its current movement state, and shapes behavioral expectations, implicitly influencing the interpretation of its intent. The dynamic signals communicate both motion intent, including speed, trajectory, or their changes, and explicit yielding or proceeding intent during priority negotiation scenarios. Together, these two layers reinforce one another, improving vehicle predictability in traffic contexts.

How form and dynamic signals reinforce each other and jointly contribute to intent legibility is illustrated in Figure 8.2.

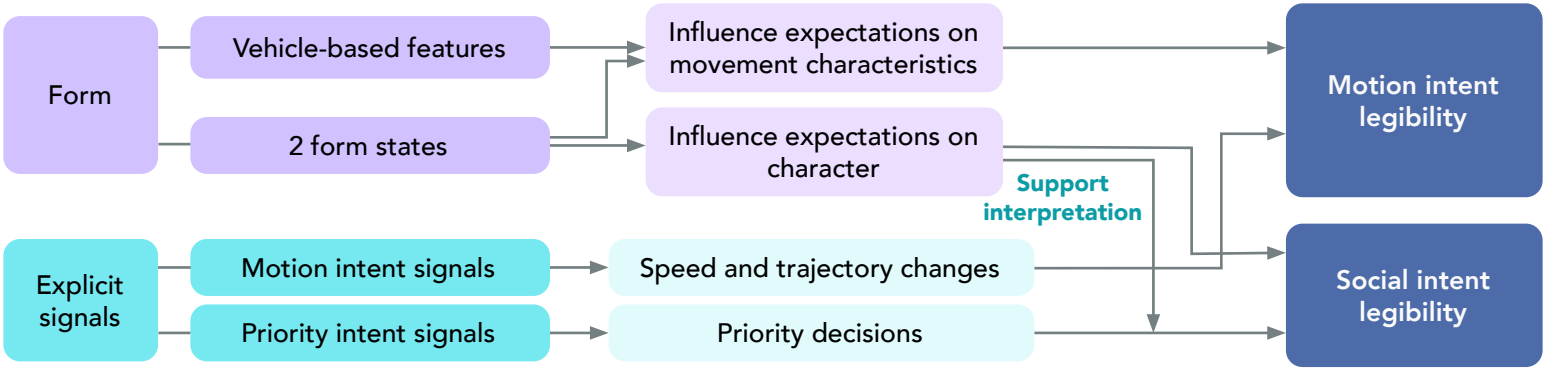


Figure 8.2: Communicative features of form and dynamic elements that reinforce each other and how they jointly contribute to intent legibility.

8.3 Design Requirements

1. The design of the vehicle form should generate expectations that align with the e-scooter's actual movement characteristics.
2. The design features, including light signals where appropriate, should support the perception of the vehicle's current movement state (including its direction, speed, and speed change).
3. The design should have a clearly distinguishable front orientation to ensure that the vehicle is identifiable, particularly in shared spaces with pedestrians.
4. The base form and the high-dominance (HD) form should have clear distinctions in visual features.
5. Without any explicit signals, the high-dominance form should be perceived by interacting RUs as more likely to move at a high speed, exhibit higher maneuverability, and taking priority during encounters compared to the base form.
6. In priority negotiation situations, the explicit light signals should enable interacting RUs to understand more clearly whether the vehicle intends to yield or proceed.
7. Each signal should remain perceptible across viewing angles relevant to its intended interaction scenario and under typical lighting conditions.
8. The signals should not interfere with each other, the rider's control, or any normal function of the vehicle.

8.4 Design Strategy

Building on existing mental models can reduce cognitive effort and facilitate quick and intuitive interpretation, which is essential in traffic contexts. Studies on intent perception in traffic indicated that cues that align with the RU's mental models enable them to interpret intent quickly and accurately, and building new communicative cues on existing conventions is a recurring strategy in intent expression in robotics and eHMI designs. This indicates an important design principle:

The design should align with people's existing mental models by adopting established conventions where appropriate, and drawing on intuitive associations where no direct convention exists.

This strategy can be applied to both the physical vehicle form and the signals. The development of the vehicle form is informed by perceptual associations identified in the visual analysis and literature involving features relating to perceived speed, stability, and affective qualities. Standardized traffic signals, primarily relied-upon cues, and visual features with established associations are adapted in the signal design.

9 Ideation

The ideation is an iterative process combining sketching and lo-fi prototyping to validate or support design ideas. The physical form and dynamic communication signals were developed in parallel and continuously influencing one another. However, for clarity, this chapter presents the ideation of these two aspects separately.

9.1 Base and HD form design

For further development on the form transformation, the base and HD form of the e-scooter were first developed to provide a basis.

Based on the precedent research, the ideation began with broad explorations through sketches. Vehicle silhouettes with exaggerated low-to-high dominance features were sketched to investigate how the identified visual characteristics could be translated into an e-scooter form and affect its overall appearance. In parallel, various front designs were also explored and evolved together with the preliminary concept of light elements (Figure 9.25). In addition, sketches of patterns in the collected high-dominance designs were made to further extract relevant visual features and support their later integration into the vehicle form. The explorative sketches are provided in Appendix 6.

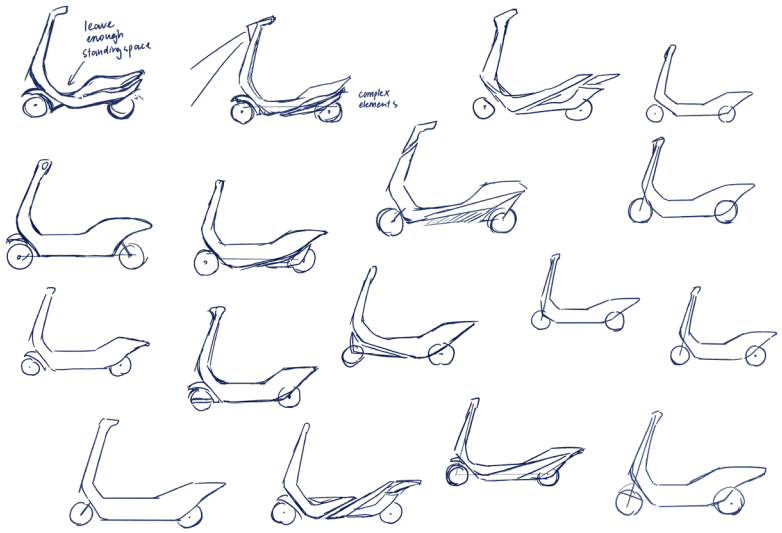


Figure 9.1: Selected sketches the base form.

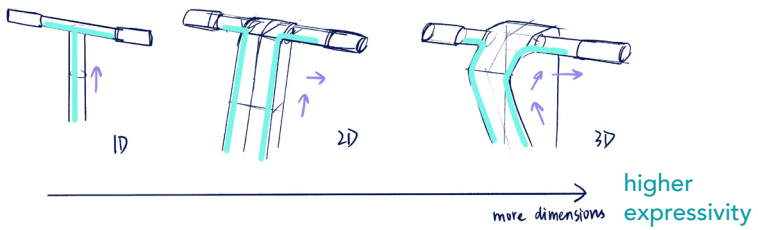


Figure 9.2. How the geometry of the vehicle front affects the expressivity of the light signals.

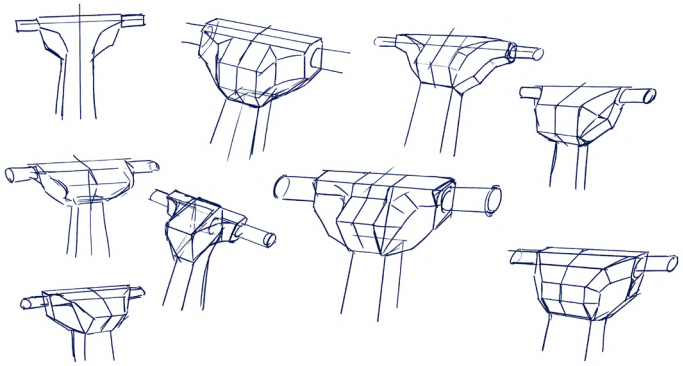


Figure 9.3: Selected sketches of the e-scooter front.

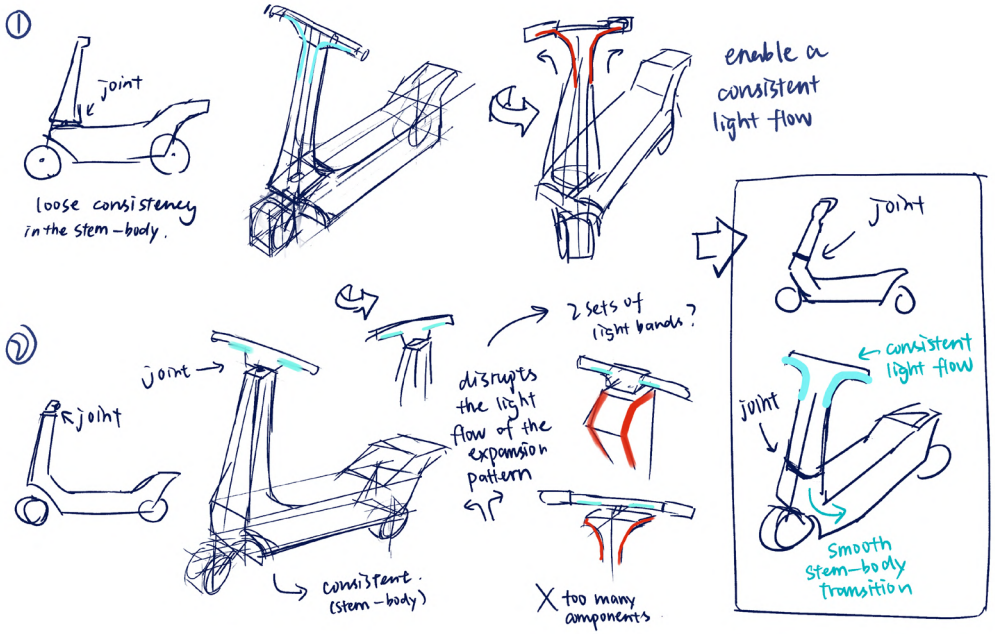


Figure 9.4: Ideation on the location of the connection point of steering joint.

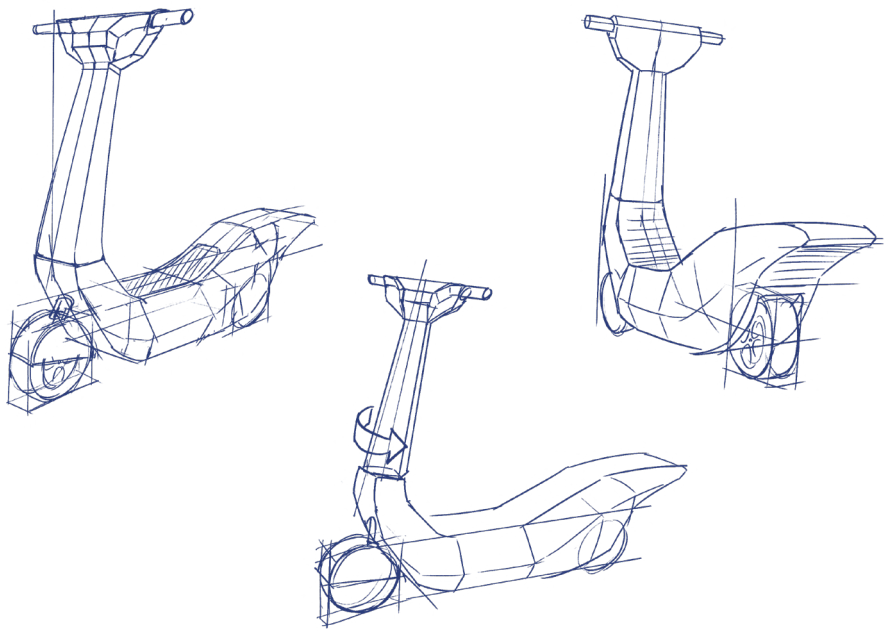


Figure 9.5: Overall design of the base form without high-dominance patterns.

The overall styling was primarily informed by the visual characteristics identified in the precedent analysis and their intended contribution to a medium-dominance level, while also influenced by personal aesthetic preferences.

The form adopts a polygonal geometry with rounded transitions to balance assertiveness and approachability. The inclined front bar and the slightly protruding front wheel create a forward-oriented posture, contributing to the perception of movement and directional intention. The body gradually increases in volume to the rear before tapering into a pointed form, contributing to a stronger perception of motion while maintaining visual balance with the forward-leaning posture. Additionally, the widened lower body increases the feeling of stability and control. Slightly enlarged wheels were adopted because larger wheels are associated with higher speed and maneuverability, while also improving speed readability.

The design of the vehicle front prioritizes the expansion light pattern, where a 3D surface is preferred for higher expressivity (Figure 9.2). It also considered the steering connection point (Figure 9.3). Positioning the steering connection att he lower part of the stem enables a continuous light flow for the expansion animation without the need for separate lighting elements, while allowing a smooth transition from the stem to the body. This resulted in a widened front "head" that integrates the handlebar and front stem into a more unified form, increasing visual presence, while creating a base area for the integrated lighting system.

Once the base form has been defined, various patterns that could convey a higher dominance level in the vehicle were explored through sketches (Figure 9.6). The patterns were developed from early explorations and designed to be consistent with the overall formal language of the vehicle. The final pattern was selected based on its coherence in styling language and simplicity, which is expected to ensure that the light-and-shadow effect is more controllable to achieve the intended transformation.

Figure 9.6: Exploration and selection of the vehicle with high dominance patterns.

9.2 Surface Geometry

9.2.1 Reducing pattern visibility

Since the body patterns are intended to convey a high dominance level, to reduce their visibility in the base form and maximize the contrast between the two form states, experiements were conducted to investigate the behavior of 3D geometries under different lighting conditions.

Figure 9.7. Experiments to explore the visibility of the pattern in the base form using two geometries.

Across various lighting conditions, the contrast level is different, and changes differently across the angles of the surfaces. This again confirms that it is impossible to achieve a perfect state where no darkened edges or surfaces are visible.

This indicates that the transformation should not aim to transition from a smooth-looking surface to a surface with visible patterns, but instead, **highlight certain visual elements** that contribute to a high-dominance appearance.

9.2.2 Grey surface

The base color should be neutral and not associated with specific meanings. Specifically, it should avoid colors that are likely to be used for the explicit signals, such as green and red, to ensure visibility and salience of the light signals. Therefore, **grey is selected as the base color**. Subsequent experiments were done on a geometry colored with light grey to examine the visibility in base form state as well as the light-and-shadow effects.

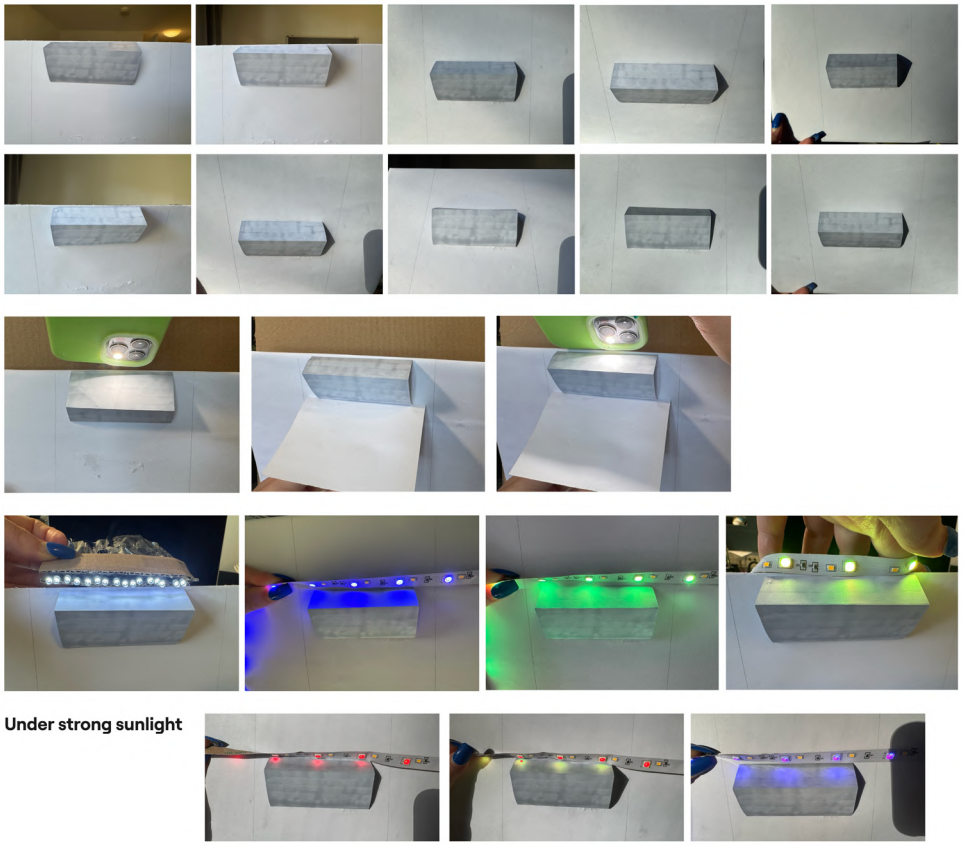


Figure 9.8. Experiment on the performance of grey-colored surfaces.

The light-and-shadow effects are still visible, and that colored lights can also add a coloring effect to the highlighted surface. However, such an effect is greatly impaired by intense ambient light. This suggests that the final implementation should adopt a light source with **higher brightness** and produces **more consistent illumination**.

9.2.3 Grey scale levels

To investigate the influence of grey scale level of the surface on the light-and-shadow effect, samples printed with five shades of grey were evaluated under regular indoor lighting (Figure 9.9).
The experiments used the same folded geometry with relatively sharp transitions to ensure observable light-and-shadow effects, and it does not represent the surface geometry in the final design.

It was observed that when white light is the main light source, there is no significant difference in the contrast between the shadowed area and the lit area across the lightness value of the surface. Only in 100% (black paper) did a slight contrast appear.
It can also be observed that the shadowed area becomes darker as the surface color gets darker, which explains why the shadow visibility remains consistent. This suggests that **lightness contrast is not affected by the lightness level of the surface**.

When using colored lights, the higher the lightness of the surface is, the more evenly the colored light can spread on the surface, suggesting that a lighter shade is preferred to increase color contrast.

Taken together, these two tests suggest that a low to medium darkness level is preferable, and light grey is selected as the base color of the vehicle.

The coloring effect is more significant and more consistent on low to medium greay surfaces

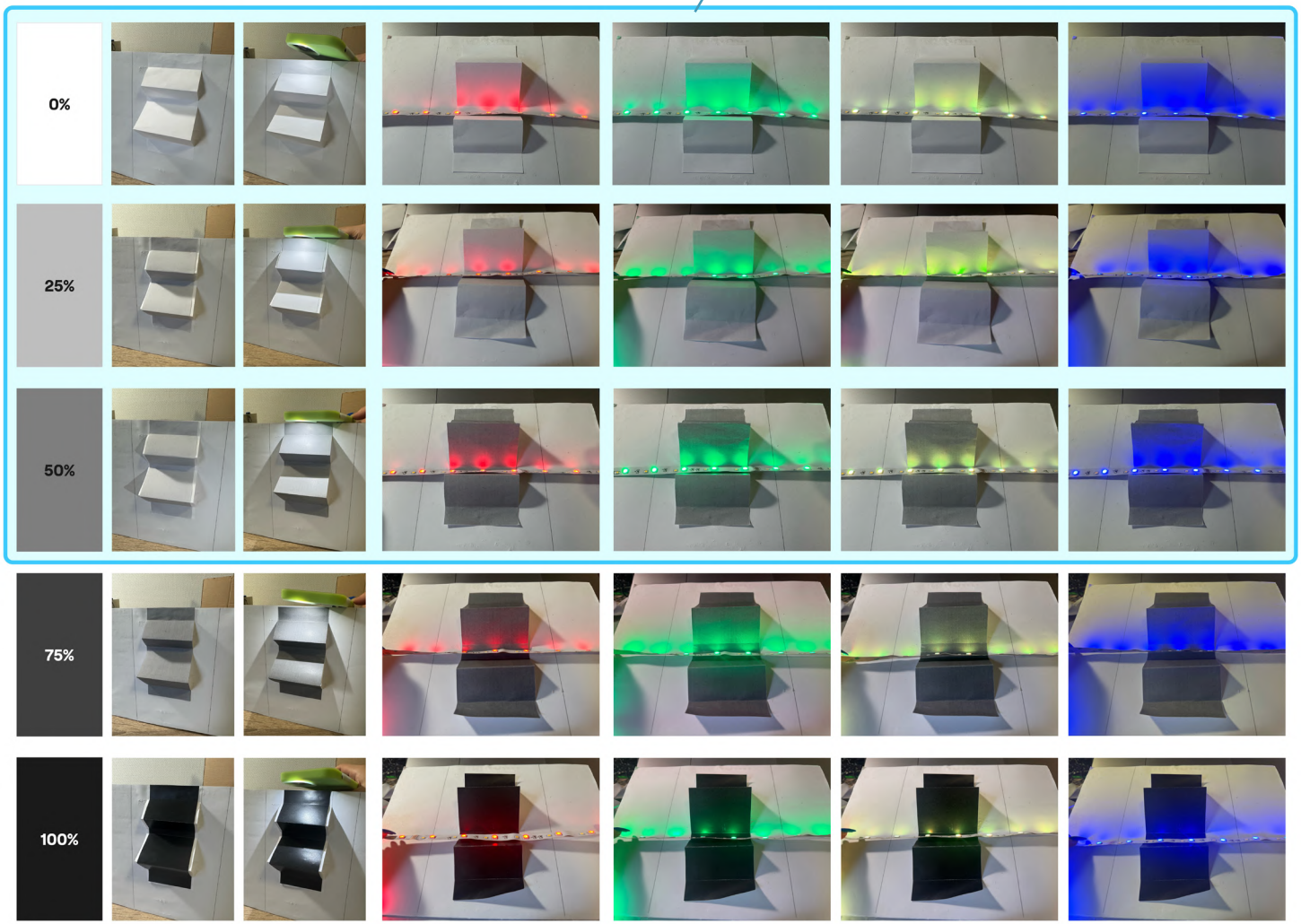


Figure 9.9. Experiment on surfaces of different shades of grey.

9.2.4 Matte v.s. glossy finishing

A test was done to compare the light effect between matte and glossy surfaces.

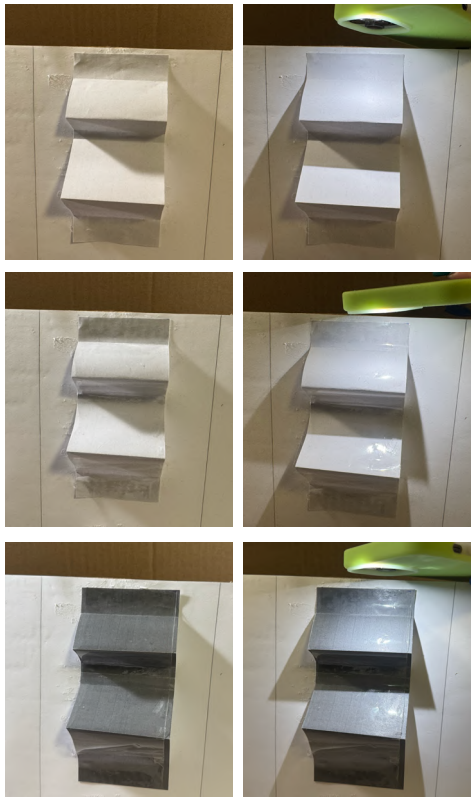


Figure 9.10: Experiments to compare matte and glossy surface finishing.

The result showed that the light and shadow effect driven by geometry remains consistent, but a glossy finish introduces highlight points, which may interfere with the perception of the designed light-form effects. This indicates that **a matte or low-gloss finish** is preferred to ensure a more stable and controlled visual appearance.

9.2.5 Defining surface geometry

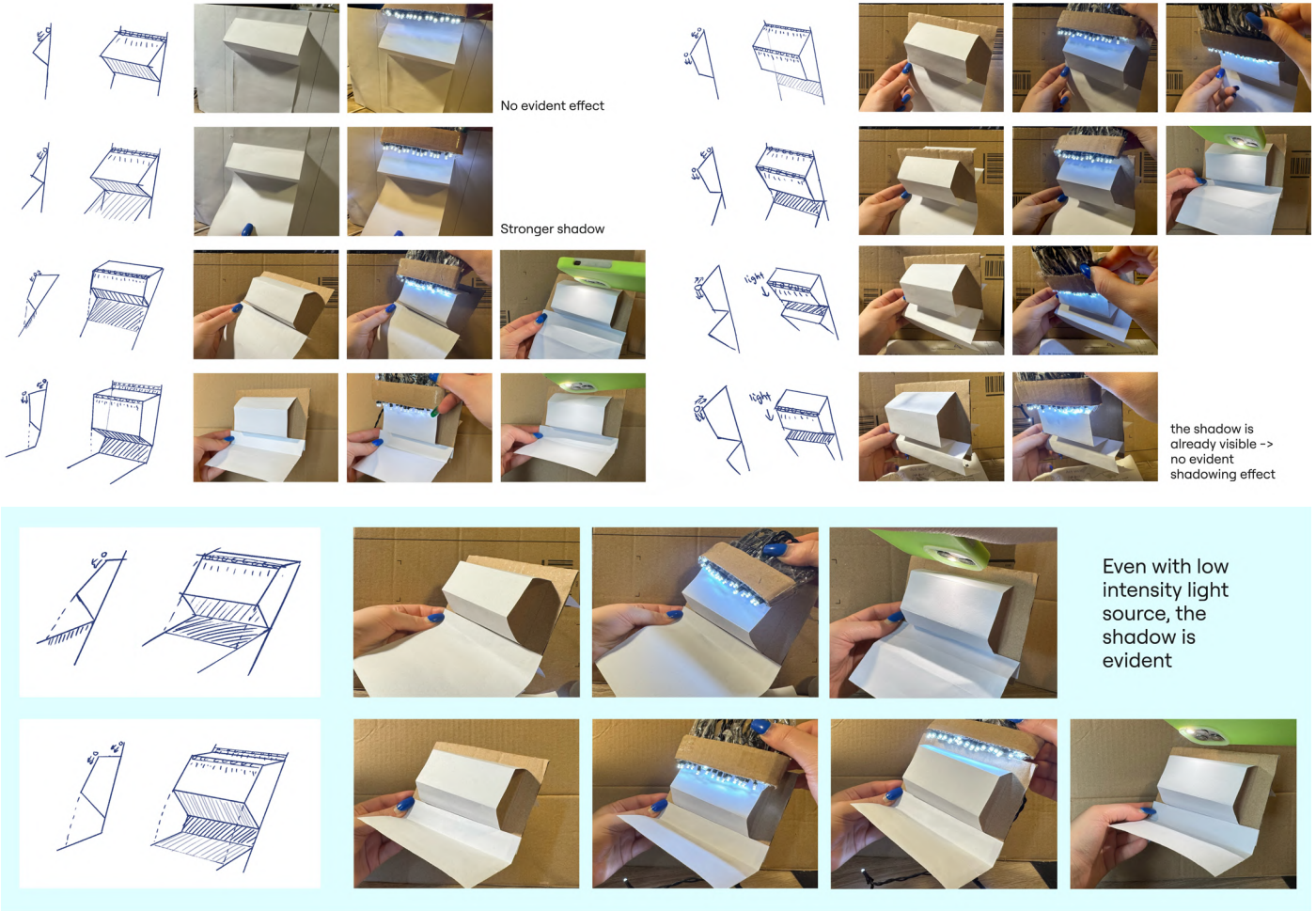


Figure 9.11: Experiments on the surface geometry to create the intended form transformation effect and the selected geometries (lower part).

To explore how the light-and-shadow effect appears on different surface geometries, various surface transitions were designed, which are expected to create an evident effect. Then they were prototyped as paper-folded polygonal forms and tested.

Two forms exhibited **the greatest contrast** before and after the structural light is added and does not have an evident lightness contrast in its baseline form. Therefore they was selected as the potential 3D geometry configuration for the high-dominance elements on the vehicle.

9.2.6 Refining surface geometry

To further reduce the visibility of the elements on the baseline form and optimize the transformation, the following approaches are tested to refine the form based on the selected configuration.

Curved surface

Curved shapes are expected to create a greater transformation effect, as in the base form the elements appear smoother, and the structural lights can create sharper transitions with the shadows. Simple geometries were used to test how curved surfaces behave under different ambient light in the baseline condition.

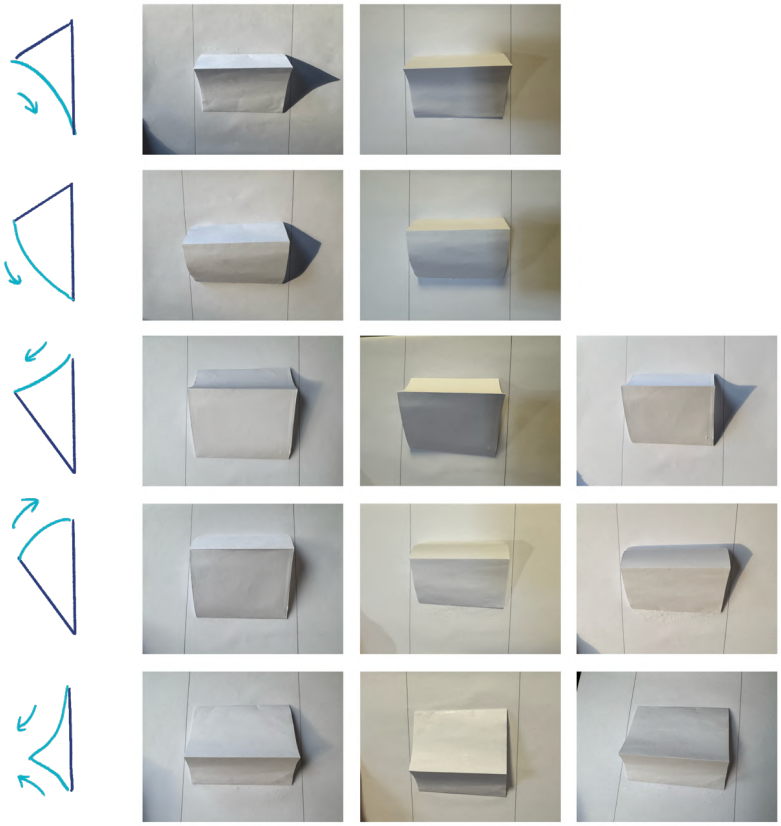


Figure 9.12: Experiments on curved surfaces.

The test showed that a curved surface often creates a darker-to-lighter transition from an edge, which emphasizes the outlines of the elements. Therefore this approach was not adopted.

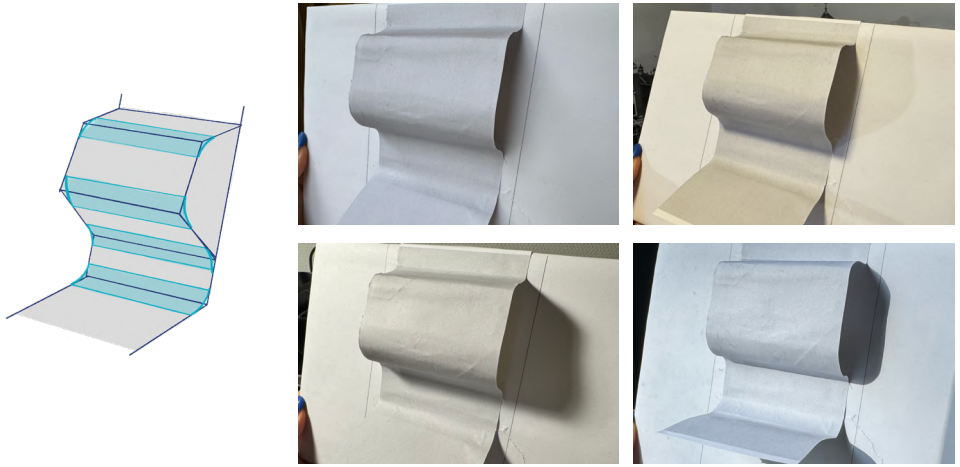


Figure 9.13: Experiments on surface geometries with rounded edges.

Alternatively, when the edges were rounded, while the general surface transition remains the same with the selected configuration, the form appears softer, suggesting this is a more suitable approach to lower the dominance level in the base form.

Countershading

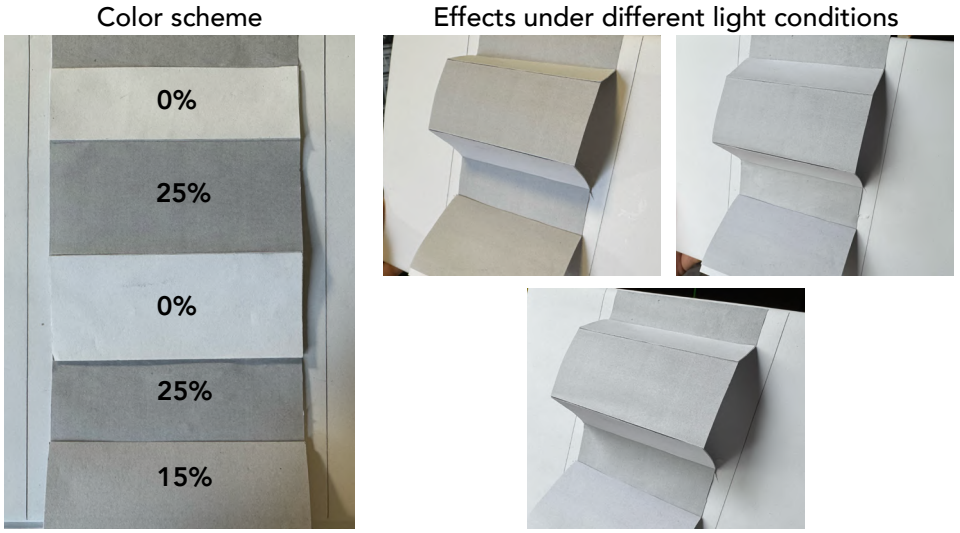


Figure 9.14: Experiments on applying countershading on the surface geometry.

Inspired by how animals conceal themselves in nature by countershading, a similar strategy can be applied to the surface geometry. The test showed that by

applying a lighter shade to the surfaces that appeared to be darker originally, the shadowing effect became less evident. With deliberate color choice, the brightness of different surfaces could even be consistent. This demonstrated the potential of this approach to reduce the visibility of the patterns in Base form.

However, further observation suggests that the light-shadow contrast varies significantly with different ambient light conditions (Figure 9.15), suggesting that one color configuration does not apply to all conditions. Across conditions, the lower part of the geometry is generally darker, indicating that the lower surface of the patterns can apply a lighter color. The later digital testing demonstrated that applying countershading can slightly reduce the shadowing effect of the body patterns, but only in certain lighting conditions, and this effect is minimal (Figure 9.16). As a result, the countershading strategy is not further pursued in the design.

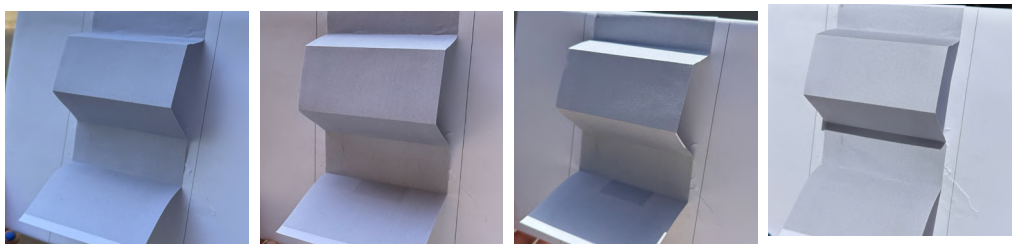


Figure 9.15: The lightness and shadows of the surface geometry under different ambient light conditions.

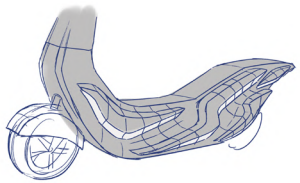


Illustration of the surfaces that applied a lighter shade in the digital tests

Figure 9.16: Digital tests on countershading.

9.2.7 Vehicle Form and Form Transformation

Informed by the experiments, the high-dominance patterns were translated into 3D surface geometry integrated into the vehicle form (Figure 9.17).

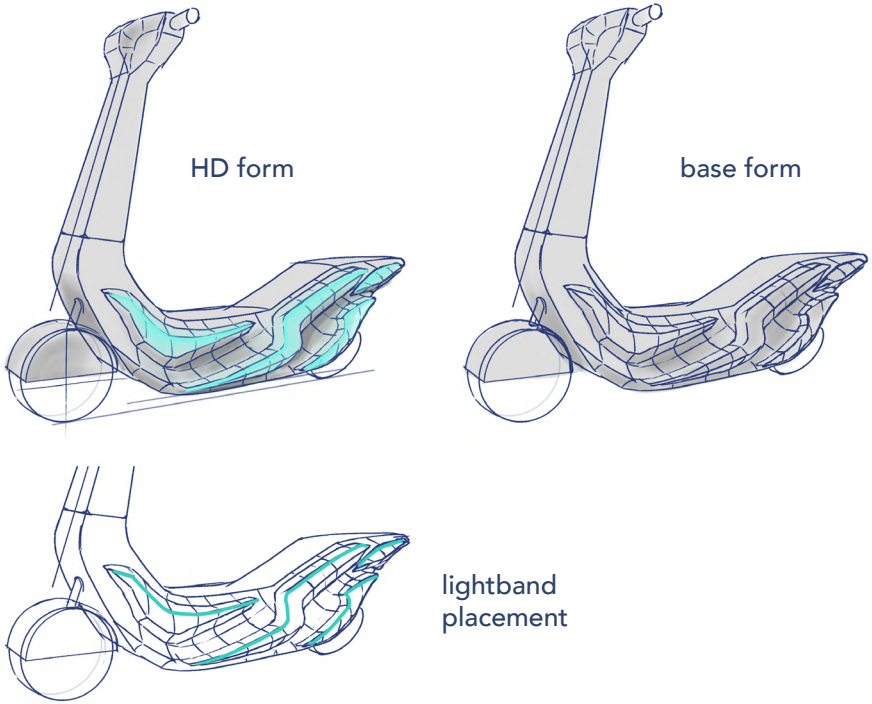


Figure 9.17: Sketches of the designed transition effect and light placement.

Lighting Design Rationale

Lightbands are selected as the primary light source to achieve the intended light-and-shadow effect based on both the precedent research and their suitability for the proposed vehicle form. Linear lighting elements are frequently employed in eHMI designs to communicate information through light patterns such as directional movement or pulsing, demonstrating potential for functioning as intent signals beyond the form transformation. Compared to light panels, they enable a rich visual language and achieve high visual salience while requiring a relatively small surface. They are more compatible with the slim form and narrow surfaces on an e-scooter, and can be easily integrated into the vehicle form by following the edges, supporting a clean, simple design. This consideration was also applied to

the explicit signals (Section 9.3), making light bands the primary medium for all the lighting elements in the proposed design. Although an SMD LED strip was used in the experiments, which resulted in visible bright spots, the final design will use a lighting system that produces consistent light and uniform illumination on the target surfaces.

The choice of light color is mainly informed by eHMI research in autonomous vehicles. Considering that the function of the form variation is to change the perceived driving style of the vehicle instead of communicating explicit intent, a color that has no associated meanings is preferred, in contrast to red and green. Cyan, yellow, and purple are identified as neutral colors in a traffic context (Bazilinskyy et al., 2020). Among them, yellow is widely applied in traffic signs, and amber ('selective yellow') is already used in motor vehicles. Compared to purple, cyan has higher perceived luminance and is more distinct against a grey background (Figure 9.18). Overall, cyan is a promising color choice for it has **good visibility, is perceivable by color-deficient individuals, and is not yet used in traffic signals** (Dietrich et al., 2018; Werner, 2018, as cited in Bazilinskyy et al., 2019). Additionally, cyan is considered aesthetically pleasing, which minimizes any possible visual discomfort (Werner, as cited in Bazilinskyy et al., 2020). Cyan is therefore selected as the light color for the structural lights.

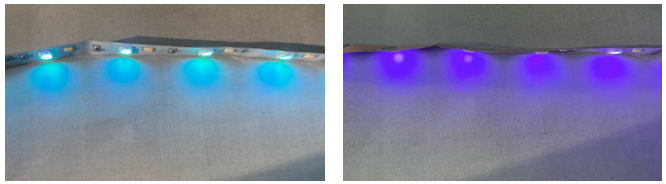


Figure 9.18. Comparison of cyan light and purple light of the same intensity on the same grey background.

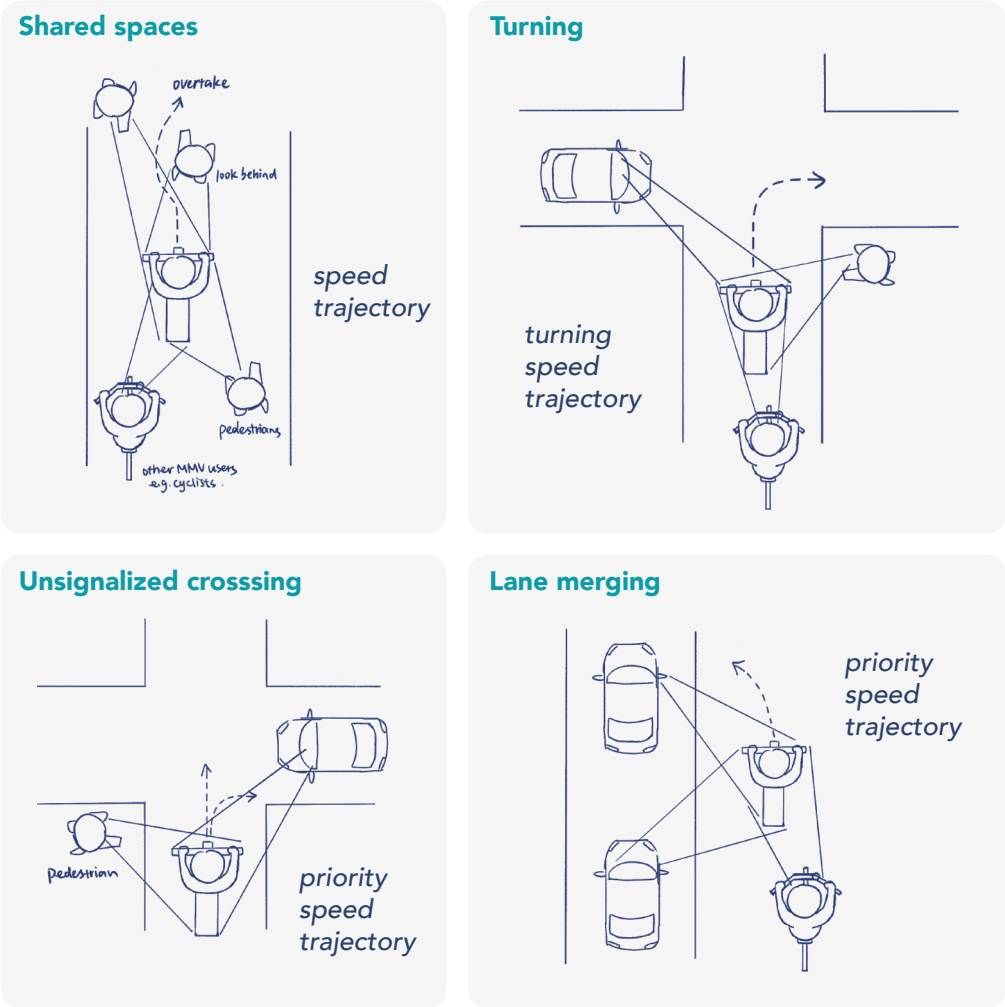


Figure 9.19. Viewpoint mapping of the four selected traffic scenarios.

9.3 Explicit Signals

9.3.1 Viewpoint mapping

To ensure the visibility of the explicit signals to different RUs, this mapping identifies where RUs (primarily) look at in the four representative interaction scenarios indentified in Section 4.

Figure 9.20. Evaluation of the visibility of different parts on the e-scooter.

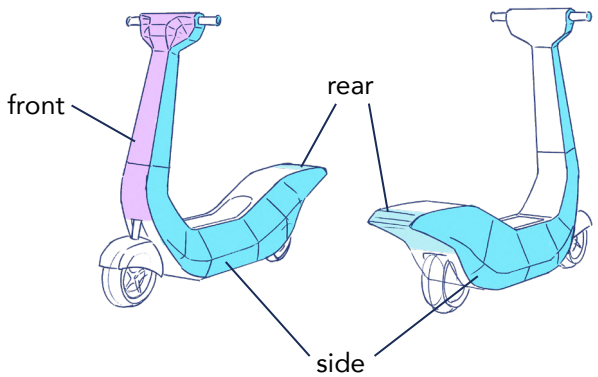


Figure 9.21. Areas of Interest (AIO) for signal integration on the e-scooter.

Informed by the viewpoint mapping, three Areas of Interest (AIOs) were defined to represent the primary vehicle surfaces for signal implementation (Figure 9.21). The AIOs were selected based on their visibility in general conditions and the feasibility of integration within the vehicle form. Specifically, the back of the stem and the deck were excluded for their low visibility because of the presence of the rider (Figure 9.20), and the surfaces on wheels were excluded due to practical limitations. It serves as a design framework for determining the placement of the signals, with the priority for each intent type (Figure 9.22) further supporting ensuring signal visibility in the relevant interaction scenarios.

The prioritization of AIOs was analyzed qualitatively, considering the most relevant intent and corresponding viewpoints in each interaction scenario. In situations involving direct priority negotiation, road users commonly encounter and view the e-scooter from the front, making it the primary AIO for explicit priority signals. This also distinguishes them from the structural lights on the body. Speed- and trajectory-related cues serve a broader function. Besides supporting general prediction of the vehicle's movement, they also contribute to the inference of priority intent. For speed-related cues, the rear is prioritized because following RUs are directly affected by changes in the e-scooter's speed and may need to react accordingly. For trajectory-related cues, the front and rear are considered similarly important. Oncoming RUs use trajectory information to anticipate the e-scooter's intended path, while following RUs rely on the same information to anticipate path changes ahead. For both intent types, side visibility is less consistently available and is therefore treated as supplementary.

Intent	AIOs				
Speed	Rear	>	Front	>	Side
Trajectory	Front	=	Rear	>	Side
Priority	Front (explicit signals)	>	Side (structural lights)		

Figure 9.22. AIOs suitable for expressing each type of intent.

9.3.2 Projection-based signals

Drawing from the conclusions from the evaluation of signaling modalities (Section 5.2), the use of projection remained uncertain. During the ideation, projection-based signlas were explored and evaluated through lo-fi prorotyping (Figure 9.23).

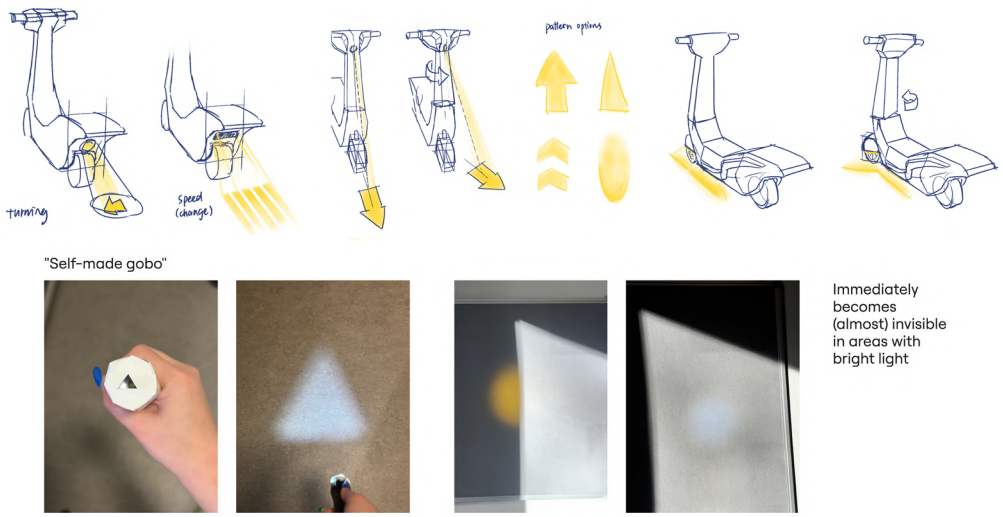


Figure 9.23. Concepts and experiments on projection-based signals.

High-intensity light can function as a projector to produce simple patterns. However, it is nearly invisible under strong sunlight, confirming that it can only act as a supplement channel. Therefore, to ensure the simplicity and practicality of this project, projection will not be further explored.

9.3.3 Front lights

During earlier design exploration, an integrated lighting system based on current e-scooter designs was proposed (Figure 9.25). The concept builds upon the perceptual associations identified in the precedent research (Chapter 5). Two horizontal light segments were adopted as gaze lights, inspired by their ability to evoke gaze-like facial features and indicating moving direction while naturally integrating into the handlebar geometry. A test with a lo-fi prototype further demonstrated that **the directionality of the vehicle is much more perceptible** with such a light shape compared to a single rounded front light (Figure 9.24), suggesting that they can serve as implicit trajectory cues. The gaze lights were designed to be cyan to align with the structural lights and to improve their distinctiveness as cyan is not a common color in vehicle lighting and has not associated meanings in a traffic context.

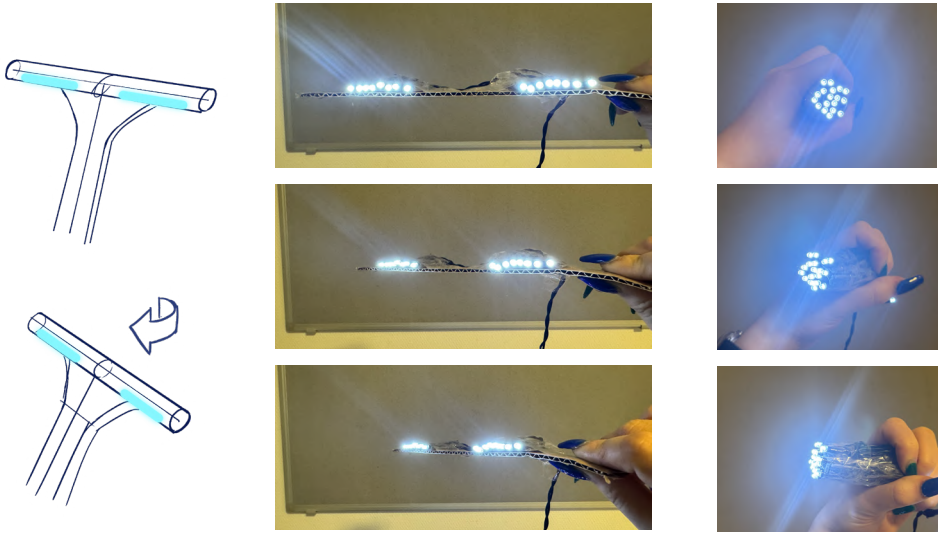


Figure 9.24: Initial concept of the gaze lights and experiments to demonstrate its

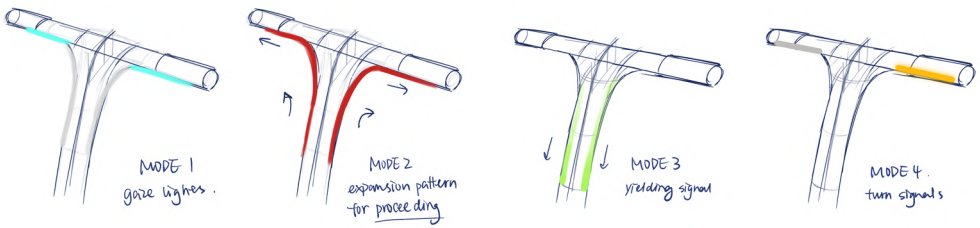


Figure 9.25: Initial concept on the integrated light signals based on the current e-scooter form.

Expanding the idea of lightbands that follow the vehicle stem, the priority signals were created by translating the dominance-related visual cues (Figure 5.13) identified in the literature into dynamic light patterns. The **upward expansion pattern** for proceeding pattern is primarily inspired by natural threat display postures, emphasizing the expansion and upward direction, and correspondingly, a **downward pattern** is proposed for yielding intent, aligning with submissive postures. To further reinforce these associations, the two patterns were differentiated through speed and color. Building on this idea, this lighting system can function as a turn indicator when only one side of the gaze light is on. After the base form of the vehicle was defined, this concept was then integrated into the proposed form (Figure 9.26). Since it already includes multiple signals, speed-relevant signals will not be placed at the front to reduce complexity.

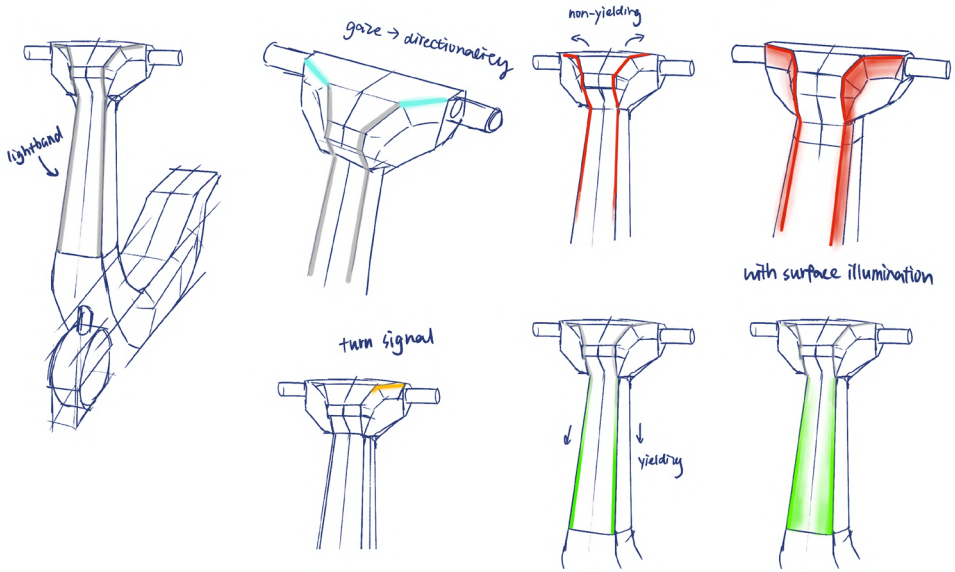


Figure 9.26: Initial concept on the integrated light signals based on the current e-scooter form.

Initially, the priority signals were intended to adopt a similar design as the structural lights for form transformation, with two symmetric light bands following the front bar and extending to the sides close to the handles, and create a coloring effect on the adjacent surfaces. This approach was intended to further improve signal visibility and form a consistent design language within the lights involving social intents. During later digital form refinement, it was found that this strategy is not ideal when functioning as gaze lights due to the geometry of the vehicle front (Figure 9.27). As a result, the final design adopts direct illumination to ensure a cleaner appearance and clearer signal expression.

Figure 9.27: Comparison between two illumination strategies on the gaze lights in renderings.

As multiple communicative signals are produced with the same lighting system, a **signal hierarchy** was established to resolve conflicts in situations where multiple signals could be present. **Turn indicators were assigned the highest priority, followed by the priority signals, and finally the gaze lights.** Turn indicators communicate an objective change in the vehicle's trajectory and follow established traffic conventions, making them the most safety-critical signal. Compared to the priority signals, the gaze lights serve as a default cue to enhance the vehicle's directionality when there is no direct interaction, making them less essential during priority negotiation situations. So the gaze lights will be temporarily overridden when the intent signals are required. This hierarchy ensures the most safety-relevant information remains visually clear in the corresponding scenarios.

Considering that the vehicle form has two variations, the front signals can also have a similar variation between a base design and a high-dominance design. This was to strengthen the difference in the overall appearance and alignment in visual language, while the structural lights are still the primary cues to affect the perceived dominance levels.

Sketches were done to explore forms for the gaze lights that vary in dominance level and are compatible with the vehicle form (Figure 9.28), which are informed by earlier precedent research (Section 6.3). The final design (Figure 9.29) then evolved from the sketches, which balances simplicity, consistency of design language with the vehicle form, and suitability for the sectional illumination strategy – illuminating different areas of the same light to achieve different shapes.

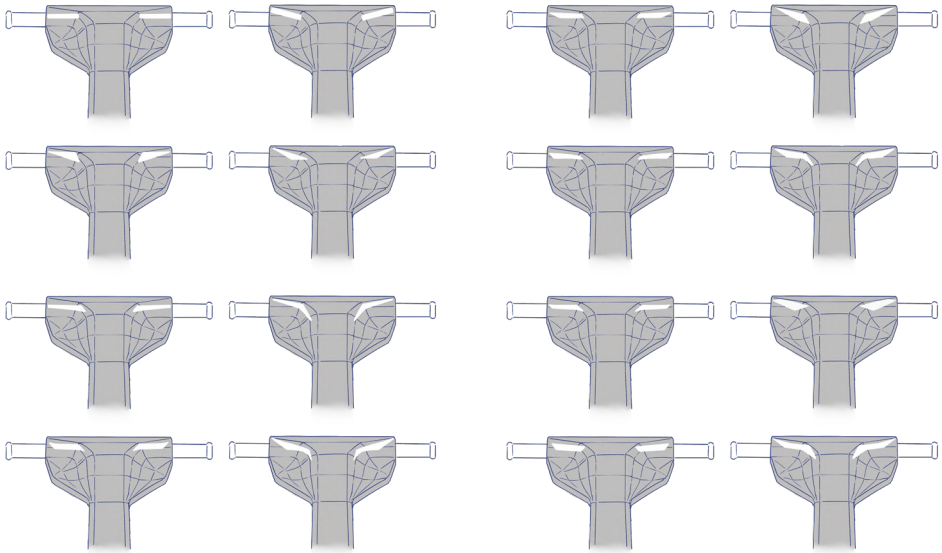


Figure 9.28: Sketches of different gaze light designs with varied dominance levels on the defined form.

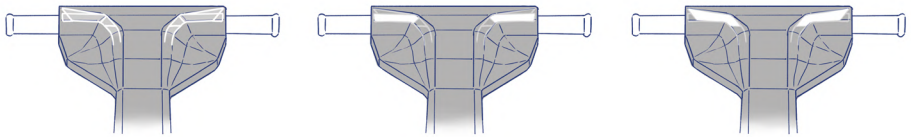


Figure 9.29: Final Design of the gaze lights.

9.3.4 Rear lights

The rear mainly conveys **directional and speed-relevant cues**. While alternative approaches such as pulsing animation or icons and different forms of integration were considered (Figure 9.30), it was decided that the rear signals should **adopt the conventional vehicle signals** to align with the essential design strategy (Section 8.4).

Similar to the front signals, further sketches were done to explore designs with varied dominance levels (Figure 9.31), and evolved into the final design (Figure 9.32).

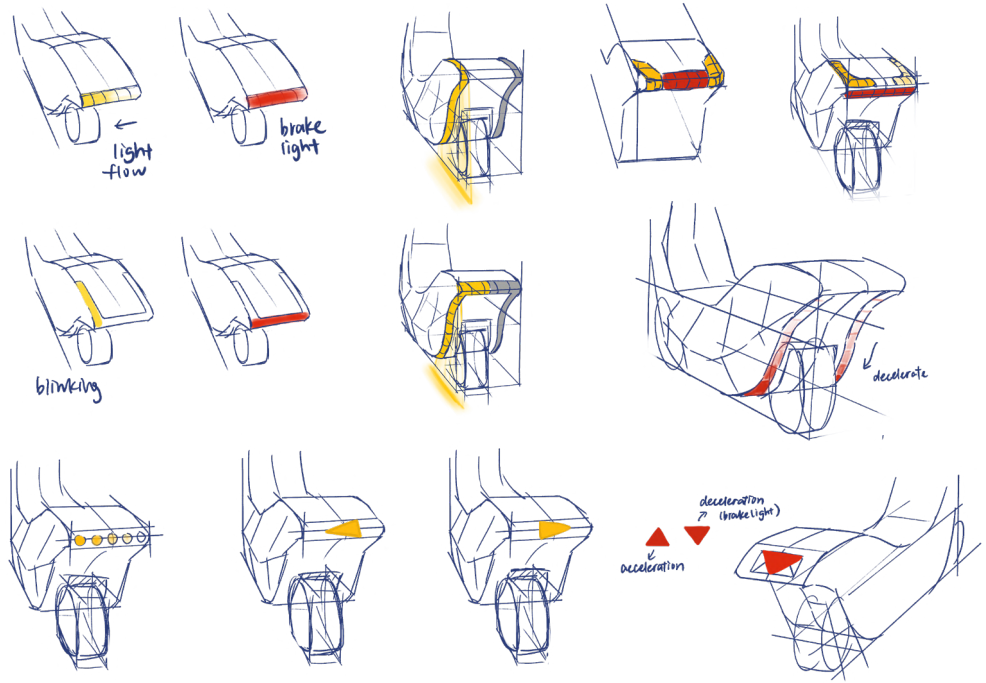


Figure 9.30: Sketches of rear signal designs.

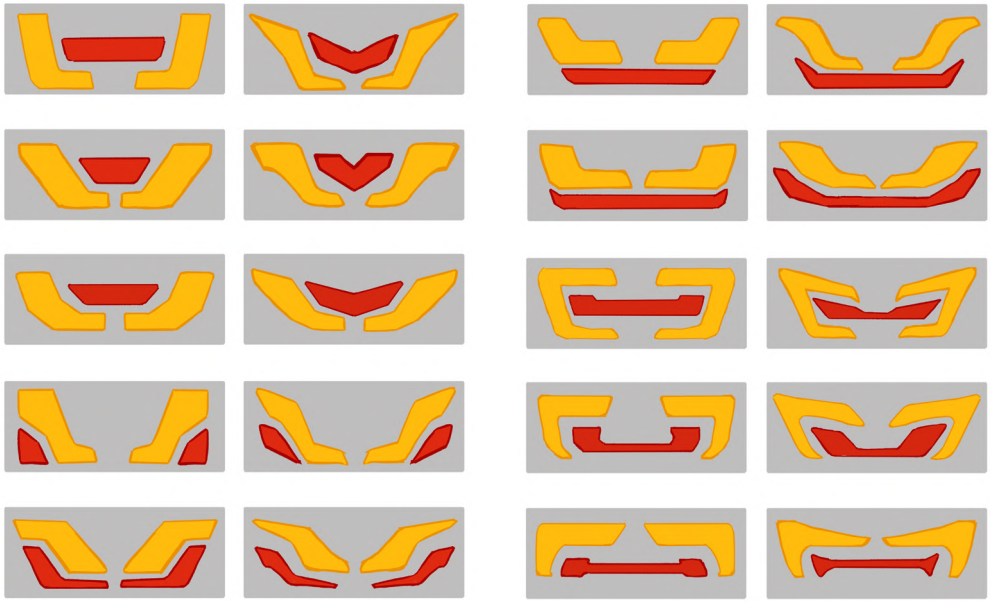


Figure 9.31: Sketches of rear light design with varied dominance levels.

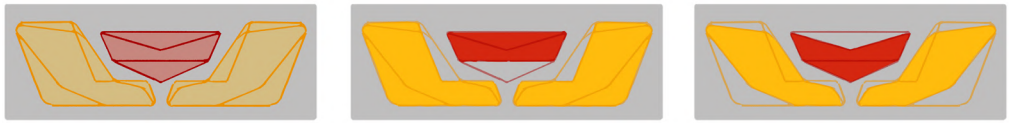


Figure 9.32: Final design of the rear lights.

9.3.5 Body lights

To avoid visual interference with the priority signals, in the side view, the placement of signals focuses on the vehicle body. Following the development of the structural lights, ideas of visualizing speed change and trajectory shift of the e-scooter were explored.

Two approaches for visualizing speed using a lightband were proposed evaluated (Figure 9.33). Building on the selected design of a pair of lightbands following the upper edges of the deck, a light signal indicating trajectory change through brightness difference were proposed (Figure 9.34).

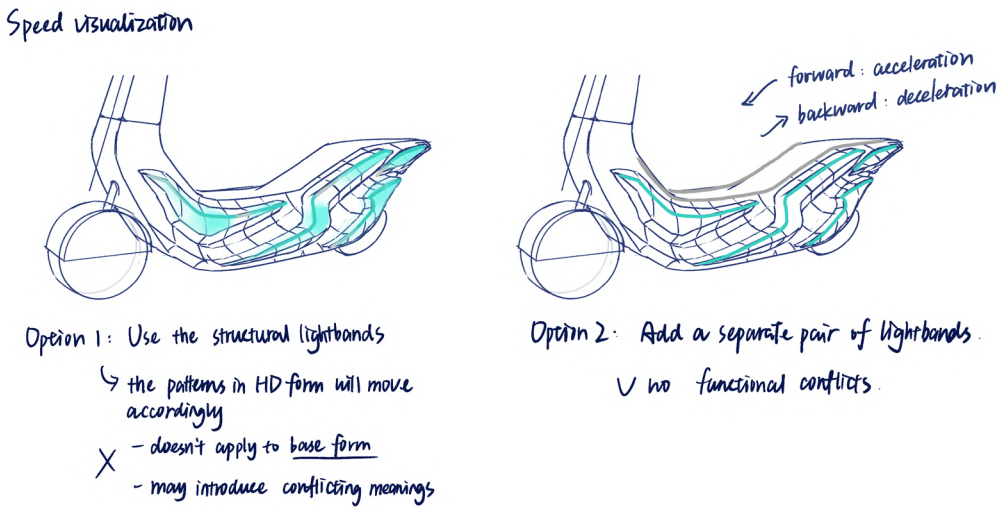


Figure 9.33: Evaluation of two concepts of speed visualization using lightbands.

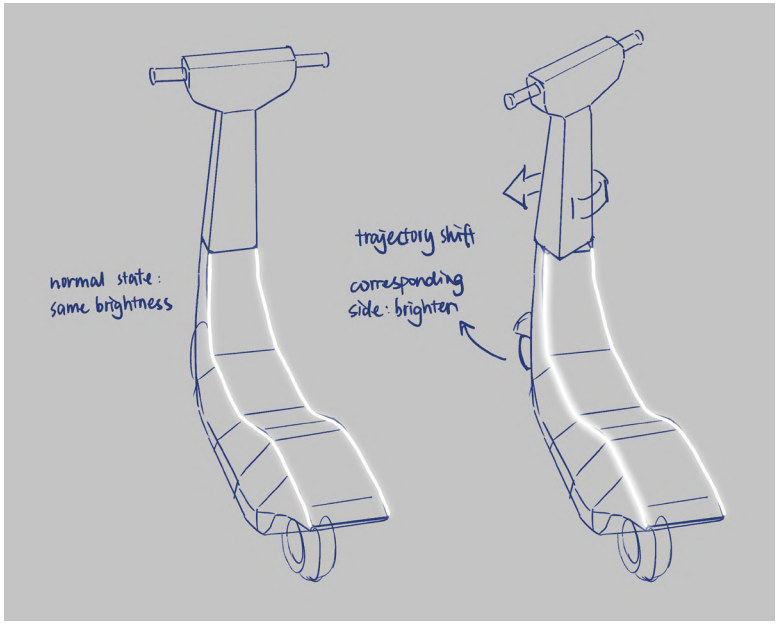


Figure 9.34: Concept of using light intensity to visualize trajectory shift.

However, the additional body light band was later considered unnecessary. First, while the structural lights are already the primary visual element for expressing the vehicle's behavioral state on the vehicle body, they introduce an additional layer of information, which risks increasing cognitive load for viewers and impairing the information clarity. Second, their intended function partially overlapped with the HD Form, which is activated under certain speed and acceleration. Third, their proposed location along the edge close to the deck made them susceptible to wear and damage from repeated mounting and dismounting of the rider.
In addition, the interactive lighting effects might lead to riders deliberately accelerating or swerving the vehicle simply to trigger such effects, potentially resulting in dangerous riding behaviors. This light element was therefore excluded from the final concept.

9.3.6 Considerations of lighting regulations

Relevant traffic regulations were reviewed to ensure regulatory compliance, especially regarding color and frequency. Road Traffic (Electric Scooters) Regulations 2024 (S.I. No. 199/2024) indicates the following design constraints on colors and frequencies for the proposed light signals:

- Lights located at the vehicle front must be white, and lights located at the vehicle rear must be red. Turn indicators are an exception, which should be amber.
- Turn indicators should show a light that flashes constantly at a rate of not less than 60 and not more than 120 flashes per minute.
- All lighting on the vehicle must not mislead or cause undue dazzle or discomfort to oncoming road users or members of the public.

As a result, the design was revised by replacing the colored front yielding signals with white light (Figure 9.35). The flashing frequency of the turn indicators and the brightness and animation of all lighting elements will be designed in a way that doesn't confuse or cause discomfort to other road users.

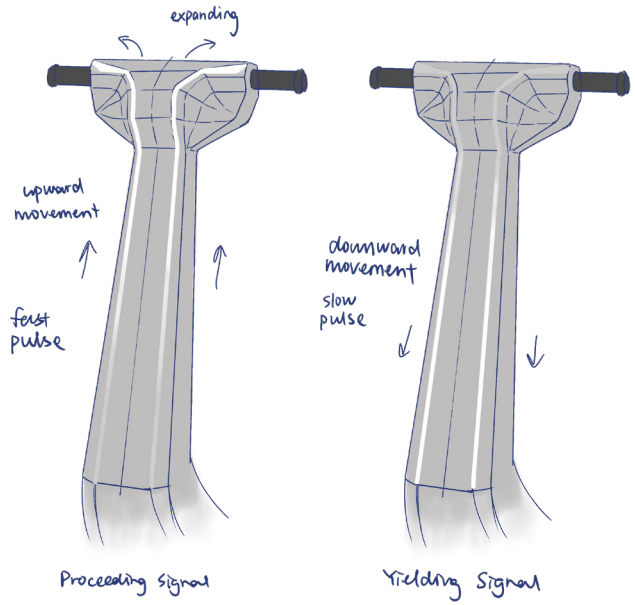


Figure 9.35: Final design of the light signals at the vehicle front, refined after aligning with regulations.

9.4 Integrated Design

In the final design, the essential features were integrated, and a potential dashboard layout was proposed (Figure 9.36). The control elements are arranged in a way that ensures they are reachable without the need to remove the hand from the handlebar while minimizing the risk of accidental operation or interference with each other. Using tabs for the brake and throttle is adopted from existing e-scooter designs such as the Segway Ninebot E22 (Segway, 2026). The priority signals and turn signals are operated using rocker switches inspired by motorcycle conventions, providing intuitive operation while being easily distinguishable. The turn indicator rocker adopts the conventional arrow symbols, and the priority signal rocker uses simplified representations of the corresponding light patterns, as no universally established symbols currently exist for yielding and proceeding intentions, while texts have limited readability and might introduce language barriers.

The power button and a screen are located on the top to ensure visibility without introducing additional protruding components.

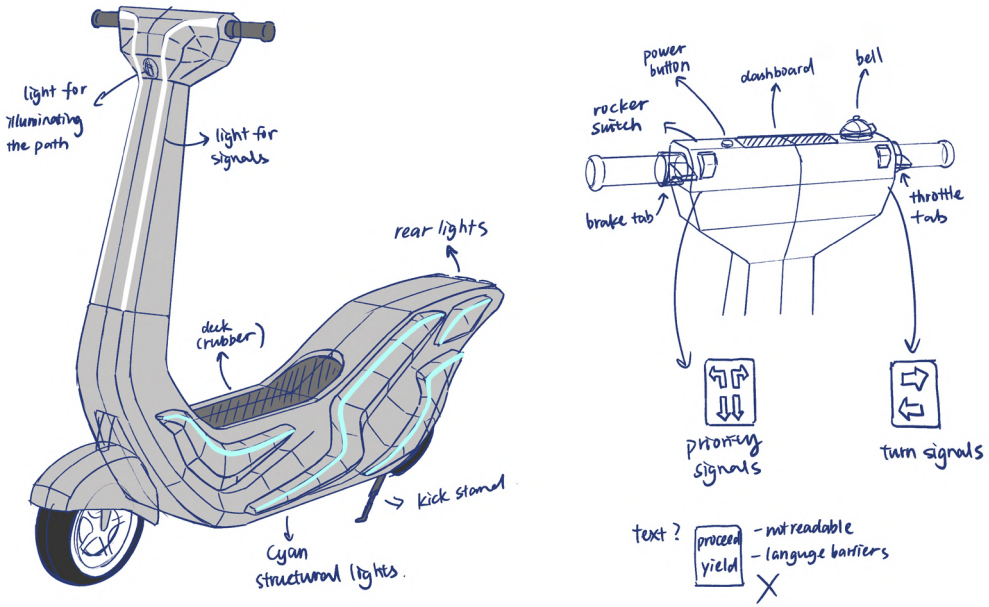


Figure 9.36: Sketch of the final integrated design and proposed control interface.

An electronic bell is installed to address the key challenge of effectively notifying other RUs of the e-scooter's presence from behind. It preserves the sound and interaction mechanism of common bicycle bells to maximize intuitiveness and effectiveness. The bell sound has been widely recognized, and it has been identified as the most consistently accepted option among different designed sound signals, while being less distractive but highly salient (Kegalle et al., 2025b). The conventional lever control supports easy operation, and provides clear tactile and positional distinction from other control elements. In addition, the housing enables a cleaner visual appearance that better integrates into the overall vehicle design.

Since the gaze lights are located on the top of the vehicle front, are relatively thin, and are primarily used to strengthen the vehicle's directionality, they are not suitable for illuminating the road ahead. In addition, they will be interrupted when other front signals are activated. A dedicated headlight was therefore installed at the lower surface of the vehicle's head to provide reliable forward illumination during nighttime without interfering with other light signals.

10 Final Design

Visient (**visi**ble + int**ent**), is a next-generation e-scooter designed with enhanced intent legibility both its physical form and dynamic light signals. It aims to reduce uncertainty during interactions, improving safety for both the rider and surrounding road users, and supporting a more pleasant traveling experience in urban areas.

Form

The formal design is guided by the vision that a vehicle's appearance should communicate how it behaves and interacts with others. Some **vehicle-based and design features** directly enhance intent legibility by improving the readability of the vehicle's current state and aligning expectations with its actual behavioral characteristics. Other **supporting local form features** are designed to provide an appropriate physical base for the lighting integration.

front lights
- improve detectability and recognizability
- support the perception of directionality

widened "head" & stem
- improve visual presence
- provide an appropriate base for lightband integration

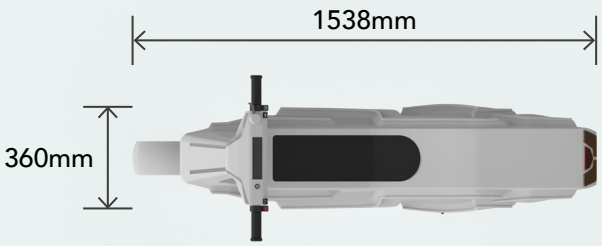
lowered steering connection point
allows a consistent light flow

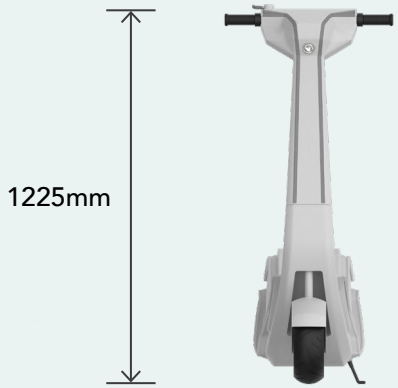
forward-oriented posture
supports the perception of movement and directional intention

slightly enlarged wheels
- supports the expectation of high speed and manueverability
- enhances speed readability

widened lower body
increases the feeling of stability and control

light grey matte finishing
- Suggest a calm, neutral state
- Optimize the visual transformation effect



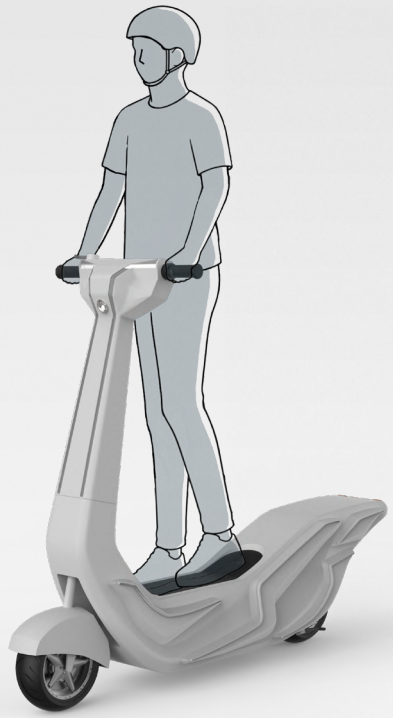


Form Transformation

The vehicle can transform between two visual forms when the rider exhibit different riding behaviors. This transformation further aligns the expectation conveyed by the vehicle's appearance with its actual behavioral characteristics.

Base form

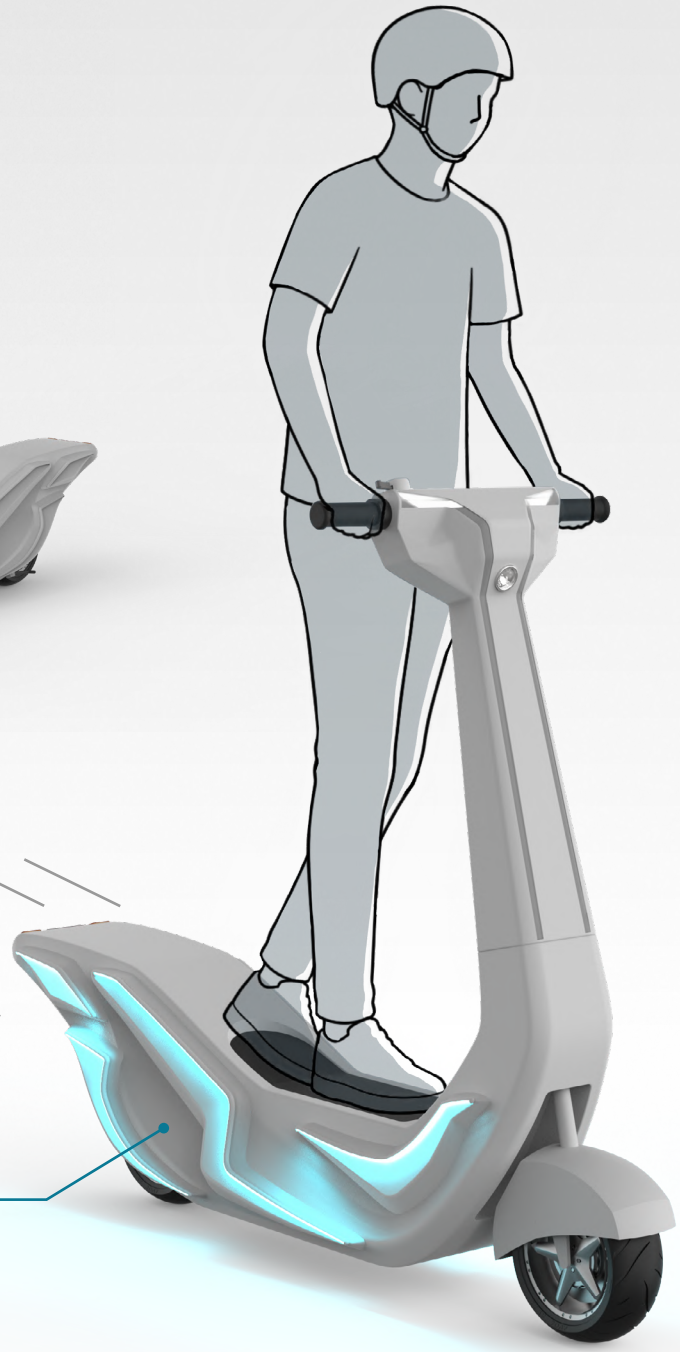
The default state of the e-scooter. Conveys the baseline expectation of e-scooters: relatively calm and controlled riding behaviors with a low likelihood to perform abrupt maneuvers.



The vehicle exeeds a speed or acceleration threshold

The structural lights are automatically activated

The light-and-shadow effect creates the visual transformation



highlighted patterns

- support the expression of high-dominance characterirstics

HD (high-dominance) form

Convey a more assertive and dynamic riding style, and expectations of higher speed, greater maneuverability, and a higher tendency to take priority during interactions.

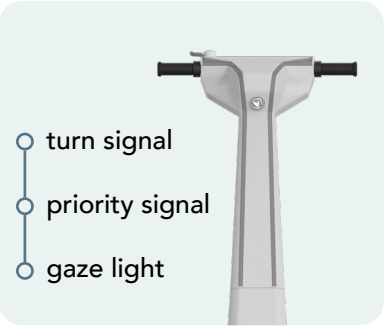
These two form states also support the interpretation of explicit priority signals by shaping behavioral expectations.

Dynamic Lights

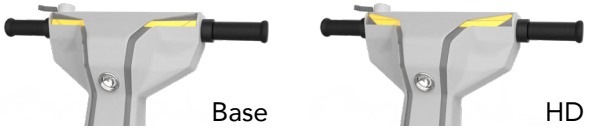
The light elements not only function as explicit light signals, but also act as a part of the formal features.

Front

Multifunctional lighting system



Turn signals



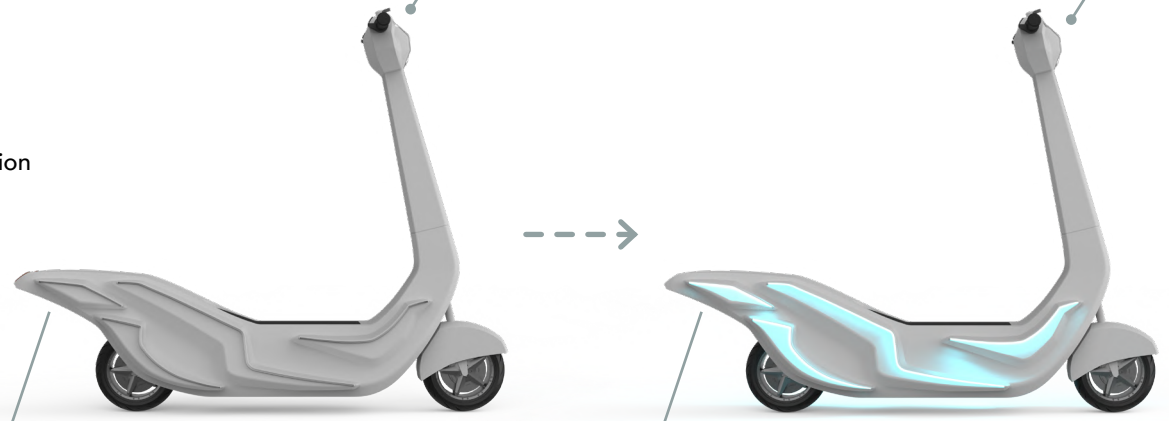
Gaze lights

The "default state" of the front lights to support the perception of the vehicle's presence and direction.

Side

Structural lights

Enables the transformation between the two form states.



Base Form

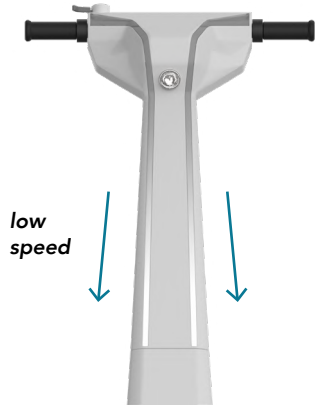
HD Form

Rear

Brake light
Turn signals

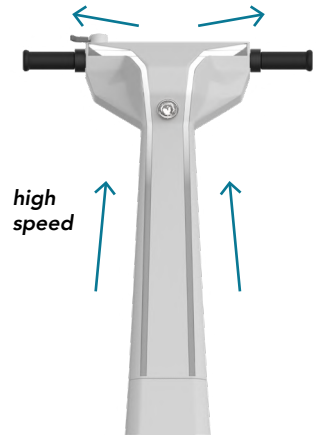
Priority Signals

Used in priority negotiation encounters to communicate the explicit intent of the rider.



Proceeding

(Can be activated in both base and HD form)



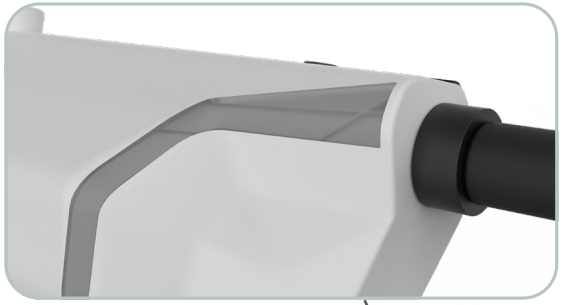
Yielding

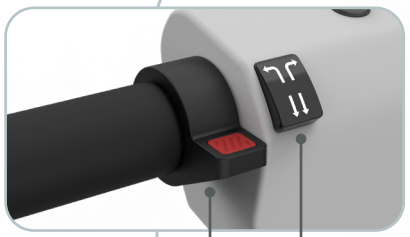
(Can only be activated in base form)

Details

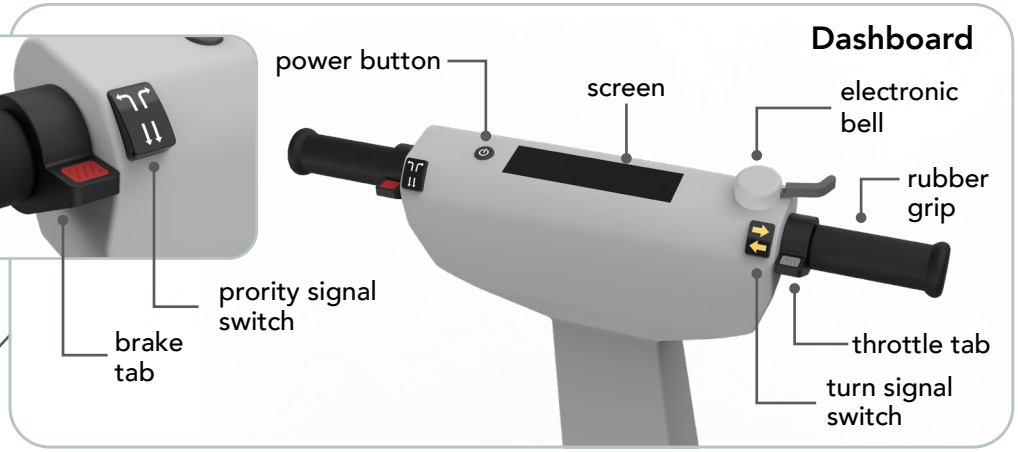
Gaze light

- Segmented LED modules
- Continuous with the front lightbands

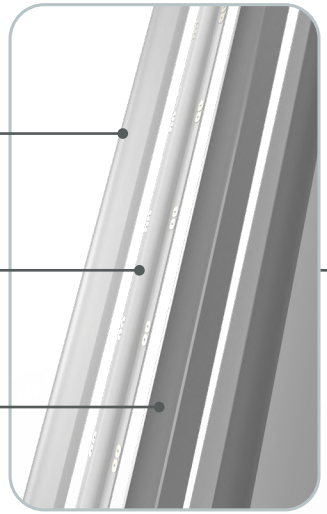




Dashboard

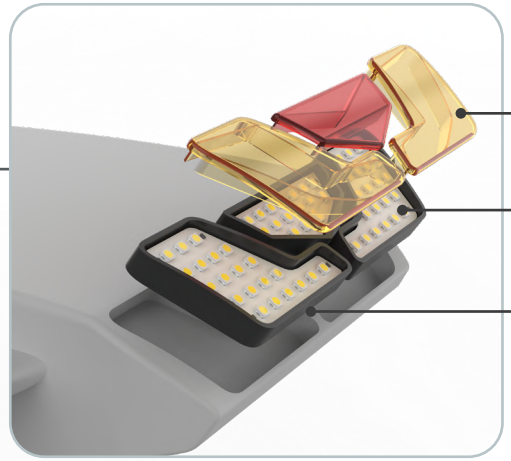


Lightband



Embedding lightbands in the stem enable a cleaner visual appearance and makes them less prone to damage.

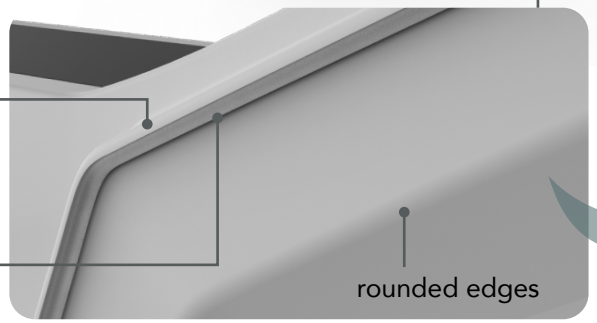
Rear light

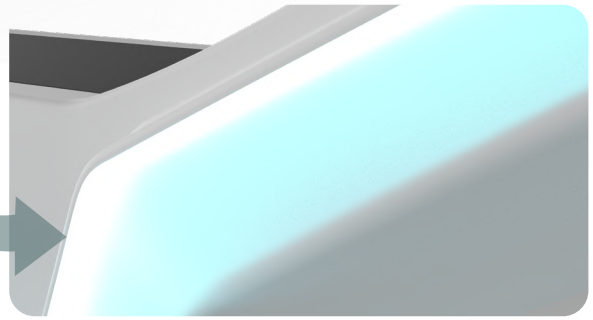


Sructural lights

Upper shell
- functions as structural support
- provides protection
- blocks upward light emission

lightband
(COB LED strip + frosted diffuser)



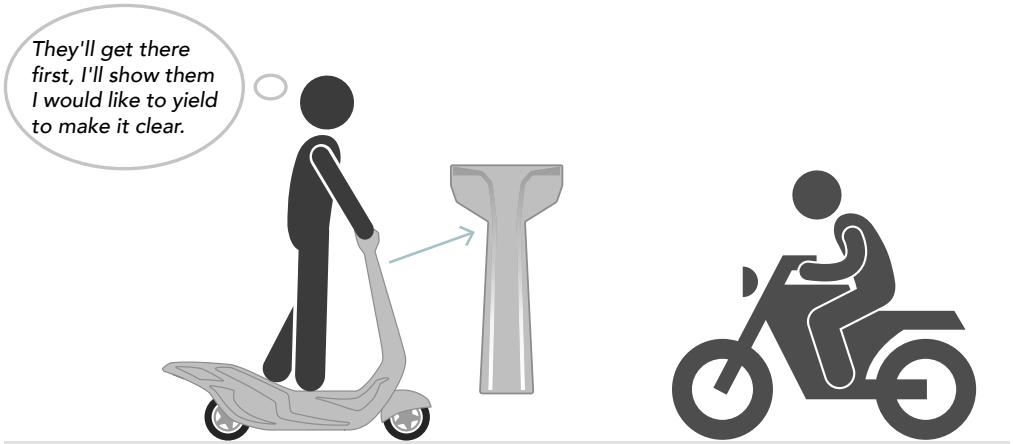


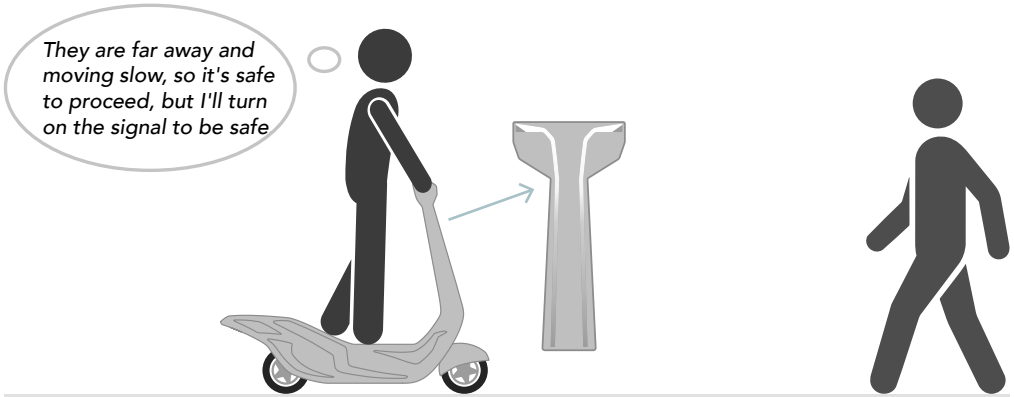
Creates uniform illumination on the intended surfaces.

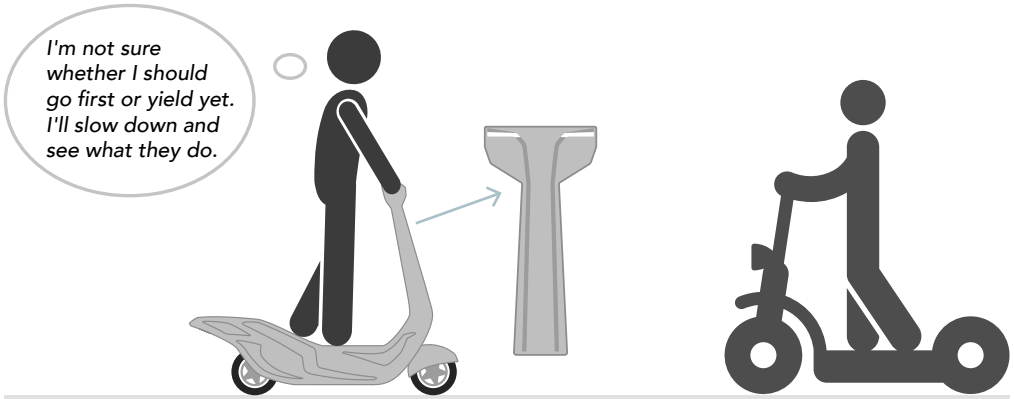
** The renders only illustrate the conceptual structures of lighting elements and do not represent the final engineering design.*

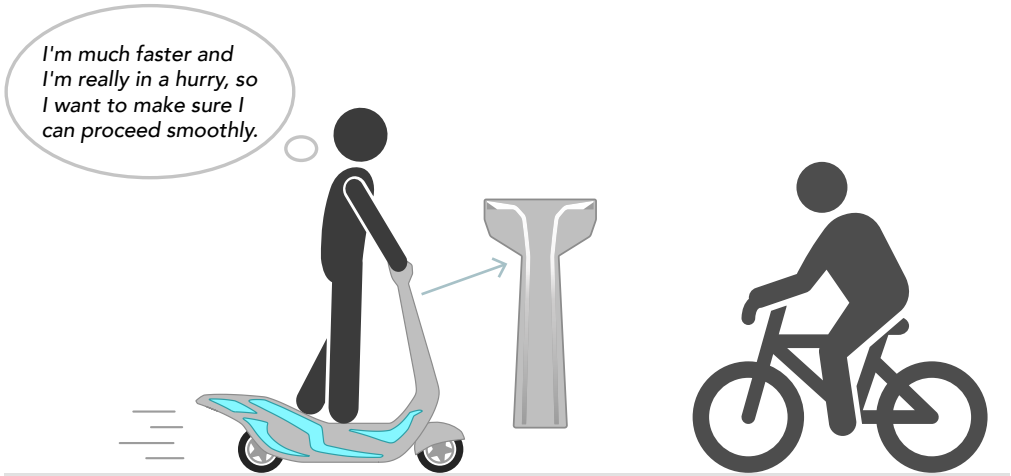
Prority Communication States

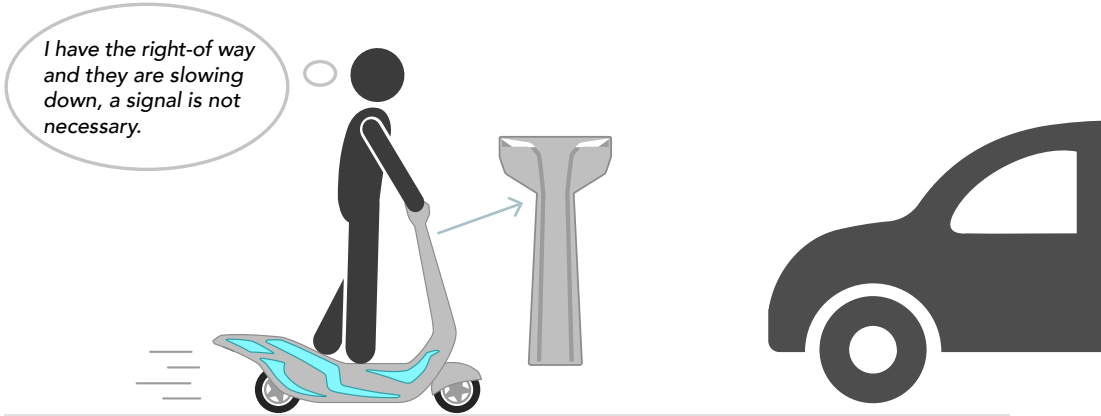
In expressing priority intent, the form transformation as an implicit layer and light signals as an explicit layer can create five different states through their combinations.
Since the priority signals are manually controlled, their activation depends on how the rider perceives the current situation, which varies across individuals, the interacting RU type, and the exact scenario.
This illustration presents an example situation of how each state may be present when encountering or approaching priority negotiation scenario.

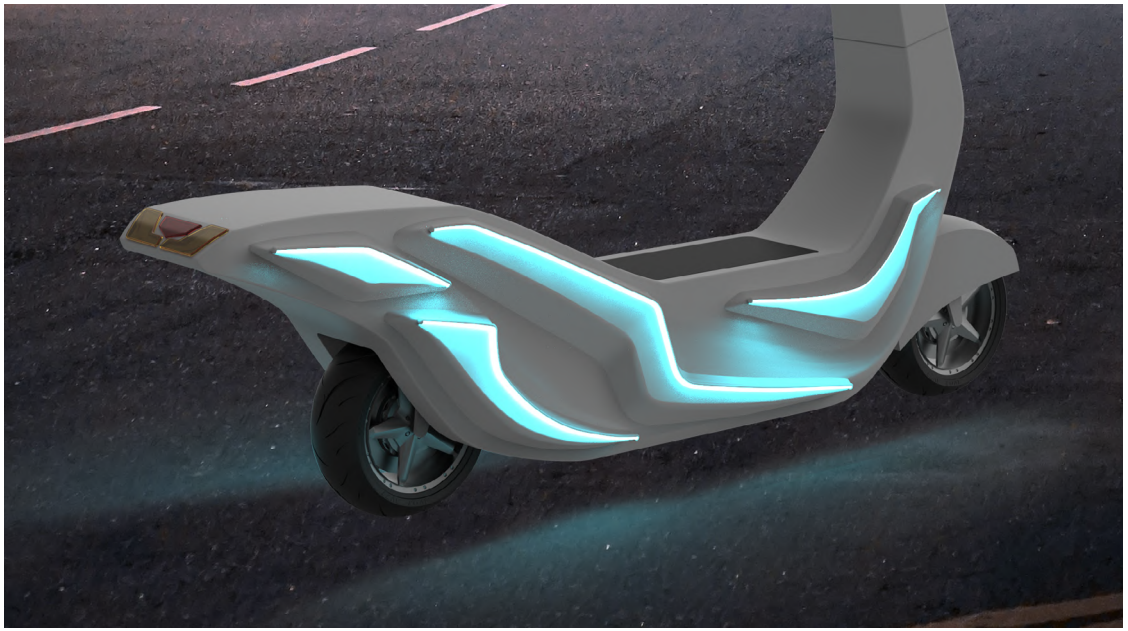












11 User Evaluation

11.1 Study Objective

To evaluate the final design, a user study was conducted focusing on the communication strategies with the highest uncertainties regarding their efficiency: the form transformation and explicit yielding signals. In the design proposal, it is hypothesized that the HD form is associated with high speed, high maneuverability, and a higher likelihood of proceeding rather than yielding during priority negotiations, and that the designed yielding signal (slow, downward pattern) can be interpreted as yielding, and the proceeding signal (fast, upward pattern) can be interpreted as proceeding.

This user study examines whether these visual design features influence users' expectations of the e-scooter's behavior and support the interpretation of its intentions during traffic interactions, and ultimately, whether the proposed communication strategies improve the legibility of the e-scooter's intentions.

The study aims to answer the following two research questions:
1) ***Does the appearance of the e-scooter affect people's expectations of their movement characteristics and social intent?***
2) ***Can the form variations and explicit light signals support intent perception in priority negotiation scenarios?***

11.2 Method

11.2.1 Study design

The study was conducted using an online survey, which consists of two sections corresponding to the two research questions:

Section 1: General Behavioral Expectations
This section focuses on how the form variations affect the expectations of the e-scooter's movement characteristics (speed and maneuverability) and social intent. A two-alternative forced choice (2AFC) method was employed, in which participants compared the baseline form and the HD form and selected the option that best answered the following three questions:
Q1 (High speed): *Which scooter looks more likely to move at a high speed?*
Q2 (High maneuverability): *Which scooter looks more likely to make sudden acceleration or direction changes while moving?*
Q3 (Proceeding tendency): *Which scooter looks more likely to proceed rather than give way when encountering another road user?*

These three questions correspond to the characteristics that are hypothesized to be associated with the HD form. Q1 and Q2 focus on motion intent, including the capability and tendency to travel at high speed and make sudden acceleration or direction changes while moving. Q3 focuses on the social intent, evaluating the perceived tendency to proceed rather than give way when interacting with another road user.

In each trial, an image of the e-scooter in base form and HD form without any explicit light signals is shown. Three viewing perspectives (front, side, rear) were used, and each pair was presented twice with a reversed left-right position to balance the order effect. These 6 image pairs were presented for each question, in a randomized order for each question, resulting in a total of eighteen trials.

Section 2: Priority Negotiation Intent
This section investigates how the explicit priority signals are interpreted in a priority negotiation scenario at an unsignalized crossing, and whether the form variations influence this interpretation.

Participants evaluated five scenarios with the e-scooter representing the combinations of form state and priority signals included in the final design (Table 8).

Table 8: Five scenarios of form state and priority signal combinations in the presented order in the user study.

	Form	Signal	ID
Scenario 1	Base	No signal	BN
Scenario 2	HD	Proceeding	HP
Scenario 3	Base	Yielding	BY
Scenario 4	HD	No signal	HN
Scenario 5	Base	Proceeding	BP

11.2.2 Participants

A total of twenty participants completed the survey. As the proposed design targets a traffic context in Europe, participants were recruited primarily from individuals familiar with European traffic environments, including residents of EU countries and people with experience living in the EU. The survey was distributed via TU Delft student group chats and the personal networks of the researcher.

11.2.3 Procedure

In Section 1, participants were instructed to select the option (A/B) that matches the question in the six trials under each question, and make the choice based on their first impression.
After completing all three questions, they can answer an optional open-ended question about what factors or visual cues influenced their choices the most.

Participants then completed Section 2. After viewing each scenario, they select the behavior that they expect from the e-scooter: Yield or proceed.
Then they were asked to rate the confidence of their judgment and the ease of interpretation on a 7-point Likert scale. At the end of this section, they can answer an optional open-ended question to describe what factors or visual cues influenced their judgment the most.

The complete questionnaire is provided in Appendix 7.

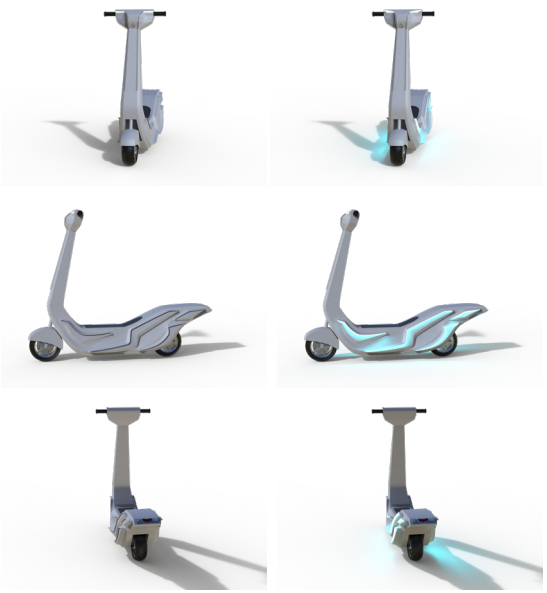


Figure 11.1: The e-scooter images used as stimuli in survey part 1.

Figure 11.2: An example of the stimuli (HN) used in section 2 of the survey.

11.2.4 Materials

All stimuli materials were created digitally. The renders of the e-scooter were generated from a design iteration that already incorporated the proposed form language, structural lights, and explicit light signals. Subsequent refinements to modelling details and non-communicative components were made after the study, therefore the final design presented in Chapter 10 may look slightly different. Images of the designed e-scooter were rendered under a daylight environment to simulate typical daytime viewing conditions. For the stimuli used in Section 2, a photograph of an unsignalized crossing in an urban setting was used as the background to provide contextual information. The rider is presented through a silhouette to avoid introducing potential bias caused by the appearance of the rider. The videos were made using stop-motion animation as an overlay on the rendered images to visualize the intended light signal patterns.

11.2.5 Data analysis

Section 1: All responses across the six image pairs were recoded according to whether the baseline or high-dominance form was selected. For each question, the proportion of selecting the HD form is calculated, and compared against the chance level of 50% to determine whether the high-dominance form was selected significantly more often than expected by random choice.

Section 2: For each case, the proportions of Yield and Proceed responses were calculated to examine how participants interpreted the e-scooter's intent under different combinations of form and explicit signals in general. Then comparisons were made between the conditions with signals and their corresponding no-signal conditions to evaluate whether the explicit signals shifted participants' interpretations towards the intended behavior. Confidence and ease-of-interpretation ratings were summarized using descriptive statistics and compared between corresponding conditions as well to evaluate whether the explicit signals improved participants' confidence and perceived ease of interpreting the e-scooter's intentions.

11.3 Results

11.3.1 Effect of form on general behavioral expectations

Table 9: Counts and percentages of HD form and base form selections in section 1.

	HD form (n)	Base form (n)	HD form (%)	Base form (%)
Q1: High speed	111	9	92.5%	7.5%
Q2: High maneuverability	97	23	80.8%	19.2%
Q3: Proceeding tendency	85	35	70.8%	29.2%

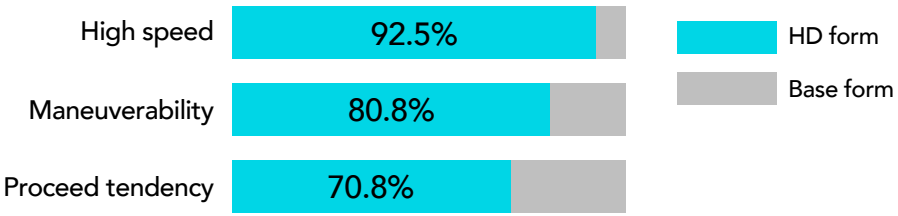


Figure 11.3: Percentages of the selection of HD form and Base form for the three questions in section 1.

For Question 1, 92.5% of responses selected the high-dominance form. An exact binomial test indicated that the high-dominance form was selected significantly more frequently than the 50% chance level ($\hat{p}$=0.925, p<0.001). For Question 2, 80.8% of responses selected the high-dominance form, which is also significantly above the 50% chance level ($\hat{p}$=0.808, p<0.001). For Question 3, 70.8% of responses selected the high-dominance form, which is again significantly above the 50% chance level ($\hat{p}$ = 0.708, p < 0.001).

In the open-ended question on the factors or visual cues that influence their judgments, all participants who answered mentioned "**light**", indicating that participants primarily based their judgments on the presence of the structural lights, and some of them specified that the color also influenced their choices. Several participants associated the lights with features such as speed, acceleration, activity, and one participant associated it with characters including boldness, speed and maybe recklessness, which aligns with the intention of the design. However, no responses mentioned the elements on the vehicle body and the differences in the overall form.

Quotes from the open-ended responses

"The lights with color and their shape in the front give the impression a bit that it might be faster"

"I associated the lights with speed or with sudden change of speed"

"The blue light is very contrasting to the general scooter making you associate the scooter with boldness, speed and maybe recklessness"

11.3.2 Effect of explicit priority signals on intent interpretation

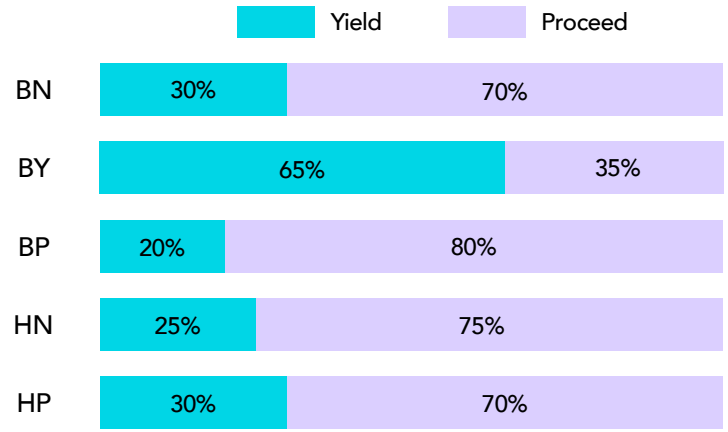


Figure 11.4: Percentages of selection of Yield and Proceed intent for the five scenarios.

Table 10: Means (M) and standard deviations (SD) for confidence and Ease of Interpretation (Ease) for the five cases.

	Confidence		Ease of Interpretation	
	M	SD	M	SD
BN	4.50	1.606	3.50	1.603
BY	4.15	1.531	4.05	1.849
BP	4.25	1.713	4.05	1.638
HN	4.25	1.585	3.35	1.531
HP	4.35	1.599	4.10	1.651

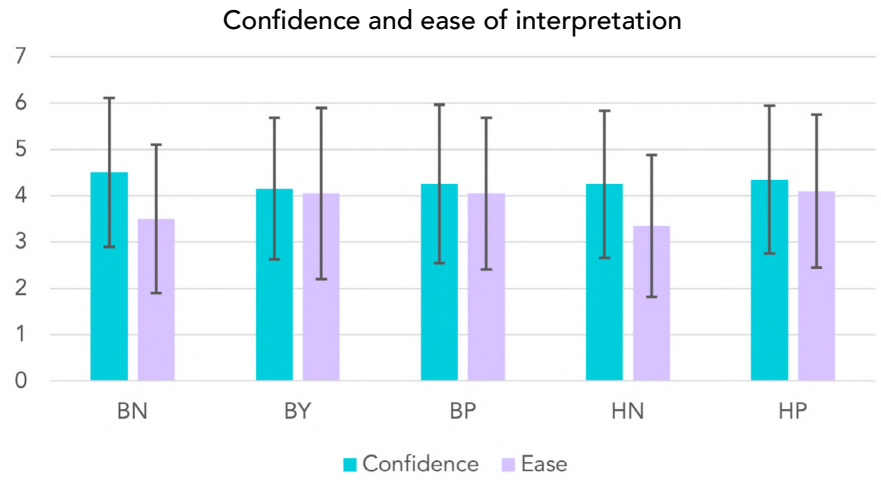


Figure 11.5: Means and standard deviations for confidence and Ease of Interpretation (Ease) for the five scenarios.

Yielding signal (BN v.s. BY)

Table 11: Results of the McNemar tests for comparisons between BN and BY.

	Yield BN	Yield BY	Proceed → Yield (n)	Yield → Proceed (n)	McNemar p
BN → BY	30%	65%	10	3	0.092

Under the base form condition without explicit signals, 6 of 20 participants (30%) interpreted the e-scooter as intending to yield. When the yielding signal was present, this increased to 13 participants (65%), corresponding to an increase of 35 percentage points. Of the 13 participants who changed their judgment, 10 changed from Proceed to Yield, whereas 3 changed from Yield to Proceed. A McNemar test indicated that this change was not statistically significant (p=0.092).

Compared with the BN condition, the BY condition showed a slight decrease in confidence ratings and a slight increase in ease ratings. However, a Wilcoxon signed-rank test indicated that neither difference was statistically significant (Confidence: Z=-0.756, p=0.450; Ease: Z=-1.085, p=0.278).

Proceeding signal (BN vs. BP; HN vs. HP)

Table 12: Results of the McNemar tests for comparisons between BN and BP, HN and HP.

	Proceed BN/HN	Proceed BP/HP	Yield → Proceed (n)	Proceed → Yield (n)	McNemar p
BN → BY	70%	80%	3	1	0.625
BN → BY	75%	70%	4	5	1.000

When the e-scooter was in the base form and without explicit signals, 70% of participants interpreted the e-scooter as intending to proceed. When the yielding signal was present, this increased to 80%. Three participants changed their answers from Yield to Proceed, and one changed from Proceed to Yield. A McNemar test indicated that there is no statistically significant change in intent interpretation (p=0.625).

Compared with the BN condition, the BP condition showed a slight increase in confidence and a slight increase in ease. A Wilcoxon signed-rank test indicated that neither difference was statistically significant (Confidence: Z=-0.289, p=0.772; Ease: Z=-1.365, p=0.172).

When the e-scooter was in the base form and without explicit signals, 75% of participants interpreted the e-scooter as intending to proceed, and this decreased to 70% when the signal was present. Four participants changed their judgment from Yielding to Proceed, and five changed from Proceed to Yield. A McNemar test indicated that there is no statistically significant change in intent interpretation (p=1.000).

Compared with the HN condition, the HP condition showed only a slight increase in confidence ratings, which was not tested as statistically significant (Z=-0.403, p=0.687). In contrast, ease ratings increased significantly after the proceeding signal was present (Z=-2.204, p=0.027).

The open-ended question produced responses that vary significantly among individuals. Some participants' interpretations align with the intended meaning, some of whom associate the patterns to accelerating and decelerating. On the contrary, some interpreted the upward pattern with deceleration or waiting, as they associated it with hazard lights or handbrakes: Some participants also reported uncertainty or conflicting interpretations of the signal meanings: "the light, but I

got really confused…" Additionally, a few participants made their judgments based on their impression of e-scooters that they tend to take priority or don't follow traffic rules.

Quotes from the open-ended responses

"The lights at the front going up remind me of when a car has its hazard lights on when temporary parking so for me it feels more like it will stop and wait"

"The light going up is for me the biggest indicator that it's waiting, I associate it with the double indicators on a car"

"…when the lights go up, it reminds me of pulling the hand brake in a car"

"I just think all scooters won't give way"

"Scooters don't tend to abide by the rules"

11.3.2 Effect of explicit priority signals on intent interpretation

Table 13: Results of the McNemar tests for comparisons between BN and HN, BP and HP.

	Proceed BN/HN	Proceed BP/HP	Yield → Proceed (n)	Proceed → Yield (n)	McNemar p
BN → HN	70%	75%	4	3	1.000
BP → HP	80%	70%	2	0	0.500

When no explicit priority signals are present (BN vs. HN), compared with the base form, the HD form produced only a slight increase in Proceed interpretations (70% to 75%). Four participants changed their judgment from Yield to Proceed, and three changed from Proceed to Yield. A McNemar test indicated that this difference was not statistically significant (p=1.000).

When the proceeding signals are on (BP vs. HP), compared with the base form, the HD form produced a slight decrease in Proceed interpretations (80% to 70%). Two participants changed their judgment from Proceed to Yield, while no participants changed from Yield to Proceed. A McNemar test indicated that this difference was not statistically significant (p=0.500).

11.4 Discussion

11.4.1 Form

The results in Section 1 indicated that there is significant evidence that the form variation can influence participants' general behavioral expectations towards the e-scooter in the intended direction. It was also found that the structural lights had a considerably stronger influence than the intended geometric form variation. In the open-ended responses, participants almost exclusively referred to the lighting elements rather than the form or body patterns. This suggests that the presence of the structural lights was considerably more salient than the intended form differences. Some participants mentioned the "bright blue color" also contributed to their judgment with the vibrancy and contrast it creates, and association with characteristics relevant to high dominance, such as high speed and boldness. Consequently, the lights effectively shift the expectation to a higher dominance, with the vehicle being perceived as more likely to travel at a higher speed, make flexible maneuvers, and claim priority during interactions.

In contrast, in priority negotiation scenarios, the form variation alone did not significantly bias participants' interpretation of the e-scooter's intention. This difference may be due to the study design. In Section 1, participants directly compare the two form variations, emphasizing the transformation effect, while Section 2 requires participants to judge each vehicle independently within a specific traffic scenario. This finding is consistent with the study by Dey et al. (2017), which indicates that the key factors that RUs rely on to make yielding or passing decisions are still kinematic cues like speed and distance rather than vehicle appearance. However, this does not necessarily suggest that form variation cannot support intent interpretation in other interaction scenarios. In crossing encounters, RUs have to judge an immediate yielding or proceeding intention and react accordingly. In such situations, explicit intent signals may naturally dominate the interpretation process. In contrast, in situations without immediate or direct interaction, such as in shared lanes, the behavioral expectations generated by the form can potentially improve the vehicle's predictability, indicating that user studies based on more diverse contexts will provide more comprehensive insights.

11.4.2 Priority signals

Overall, the explicit priority signals did not consistently improve participants' interpretation of the intended vehicle behavior. Neither the yielding nor the proceeding signal produced statistically significant changes in interpretation, or improved confidence and ease of interpretation compared with the corresponding conditions without the signals (except for the HN vs. HP comparison). One possible explanation is that the perceived intention communicated by the vehicle form conflicted with that of the priority signals. Even without the explicit signals, 70% of participants interpreted the base-form vehicle as intending to proceed, suggesting that the base form leads to an interpretation inclining towards proceeding. Combining the responses from the open-ended questions, a number of participants interpreted both priority signals as yielding intent. This conflict may also explain the slight decrease in confidence in the BY and BP conditions compared to BN.

Although the yielding signal did not produce a statistically significant effect, the proportion of participants interpreting the vehicle as yielding increased from 30% to 65%. This substantial increase suggests that the yielding signal likely conveyed the yielding intention, but the effect may not be strong enough to overcome the participants' basic expectation that the scooter would proceed, or too small to produce a significant result with the current sample size. In contrast, the proceeding signal resulted in considerably more varied interpretations. According to the open-ended responses, this may be due to the different kinds of associations they refer to. Those whose interpretation aligns with the intended meaning commonly associate the pulsing speed or moving direction of the patterns with acceleration and deceleration, which are indicators of proceeding or yielding intent in current traffic. Those who interpreted differently used familiar automotive conventions, associating the blinking pattern with hazard lights, or the upward direction with pulling up the handbrake. These conflicting mental models likely contributed to the inconsistent interpretation of the proceeding signal. These findings are similar to the findings in a study on bio-inspired eHMIs (Oudshoorn et al., 2021), which found that the proposed bio-inspired eHMI designs had a low performance score, which might be due to a lack of familiarity with these visual cues.

Although only the comparison between HN and HP reached statistical significance, ease of interpretation ratings showed a consistent increase across all three conditions with the signal, compared to the corresponding conditions without it. In contrast, confidence ratings did not exhibit a similar pattern. Interestingly, participants found the scooter significantly easier to interpret when the proceeding signal was present in the HD form. However, the proportion of Yield interpretations increased slightly from 25% to 30%, which is the opposite of the intended effect. This may suggest that the priority signals generally made participants feel that the vehicle's behavior was easier to interpret, regardless of whether the interpretation aligns with the intended meaning, which might be because the salience of intent expression increased. This is also consistent with Oudshoorn et al. (2021), which suggested that the one with coloration has a relatively higher performance because the visual change is more evident and attention-grabbing.

11.4.3 Conclusion and design implications

Overall, the form transformation enabled by the structural lights successfully influenced participants' general behavioral expectations of the vehicle in the intended way, but had little influence on intent interpretation during specific traffic scenarios. In terms of the explicit signals, the yielding signal demonstrated potential in communicating yielding intention, while the proceeding signal produced inconsistent interpretations. Although the explicit signals did not consistently improve interpretation accuracy, they can potentially improve the ease of intent interpretation by improving the salience of the vehicle's communication cues.

The mixed interpretations of proceeding signals are due to individual differences in the existing cues they associate the light pattern with. While the priority signals were originally inspired by biological behaviors, where elevation and expansion are used to enhance visual dominance or display threat, and a lowered posture reduces dominance, participants more frequently interpreted the animation patterns through traffic-related associations, such as handbrakes, hazard lights, or speed change. This suggests that when encountering unfamiliar communication cues, RUs tend to rely on associations with existing traffic conventions rather than abstract natural inspirations.

In the current version, introducing them both may not efficiently convey the corresponding intents. Therefore, future improvement should focus on strengthening the distinction between the two animation patterns and forming stronger associations with corresponding traffic-related cues. These findings also provide insights into the future development of vehicle-level communication strategies, which will be further discussed in the next section.

12 Discussion

12.1 Reflection on the Project

This project investigated how the physical embodiment of an e-scooter can enhance the legibility of vehicle intent in traffic interactions through the combination of static form and dynamic lighting. The result is a proposed e-scooter design that integrates formal features and dynamic light signals to improve its intent legibility through general behavioral characteristics and immediate interaction intentions.

The vehicle form integrates vehicle-based and design features to strengthen its intent expression. Particularly, the transformation from the base form to a high dominance (HD) form activated by the structural lights on the body, which is intended to form an expectation of a higher tendency to move at a high speed, high maneuverability, and take priority during interactions. For explicit signals, conventional signals were retained where appropriate, while new communication strategies were introduced only where current solutions are insufficient, particularly for priority negotiation.

While previous research on traffic communication has primarily focused on light-based explicit signals and eHMIs, which are additional communication interfaces. In contrast, the proposed design takes lighting as an element that shapes the form, and uses form as an implicit communication layer to influence people's expectations. This integrated approach has received little attention in the design of micromobility vehicles.

The user study partially supports the proposed design strategy. The findings suggest that the form transformation successfully influenced participants' general expectations of the vehicle's behavior, indicating that vehicle embodiment can shape expectations regarding characteristics such as speed, maneuverability, and interaction style. This influence is insufficient to bias participants' interpretation of priority intents in crossing encounter scenarios, but it remains uncertain whether the form variation can support intent perception in other key interaction scenarios.

In terms of the explicit signals, the yielding signal demonstrated potential in communicating yielding intention, whereas the proceeding signal produced mixed interpretation, indicating that the distinction between the two animation patterns and the associations with corresponding traffic-related cues might not be strong enough. Overall, although the light signals can potentially support intent interpretation by improving the salience of the vehicle's communication cues, the animation patterns require further refinement and validation. These findings are consistent with current eHMI research, where a signal that clearly expresses yielding or proceeding intent is still being explored. More broadly, this indicates that while dynamic lighting can effectively communicate that the vehicle is conveying information, establishing a universal visual language for novel interaction signals remains a key challenge in mobility research and design,

Beyond the proposed design itself, the project demonstrates a systematic approach to developing intent expression strategy through vehicle embodiment, informed by design precedents, perceptual associations, and traffic conventions. The design and findings can inform design and research for future e-scooter development, offer transferable insights for other MMVs and the broader mobility field on improving intent communication in mixed traffic environments.

12.2 Evaluation of the Proposed Design

Beyond reflecting on the RtD process, the project outcome - the proposed design - is further evaluated from a product design perspective using the Feasibility, Desirability, Viability (FDV) framework.

Feasibility

The proposed design was framed as a "next-generation e-scooter design" that is realizable in the near future. To support this objective, the overall vehicle architecture remains mostly the same as current e-scooters, while the communicative elements rely on commercially available technologies, particularly LED modules and conventional electric control systems. Therefore, the design is considered technically feasible.

The challenges lie in engineering implementation. Because of the vehicle head geometry, the protruding body patterns, and the countershading color scheme, the housing complexity increased. Compared to conventional e-scooters, the tooling and injection molding process will be more demanding. The additional

lighting modules also require more complex electronics integration, including wiring, mounting, and assembly. Although these factors will increase manufacturing difficulty, they are not expected to prevent the realization of the proposed design.

Desirability

The proposed design introduces additional value by improving the legibility of the e-scooter intent during traffic interactions. Riders who frequently experience uncertainty during space sharing or direct encounters may consider it a meaningful quality given that it may improve confidence and perceived safety. The dynamic form transformation may also appeal to users who appreciate expressive or technologically advanced products, especially considering that e-scooter users are predominantly younger adults.

However, the communicative features and functions may introduce usability trade-offs that influence user acceptance. Compared to current e-scooters, the proposed design adopts an enlarged vehicle body with a more complex geometry, which

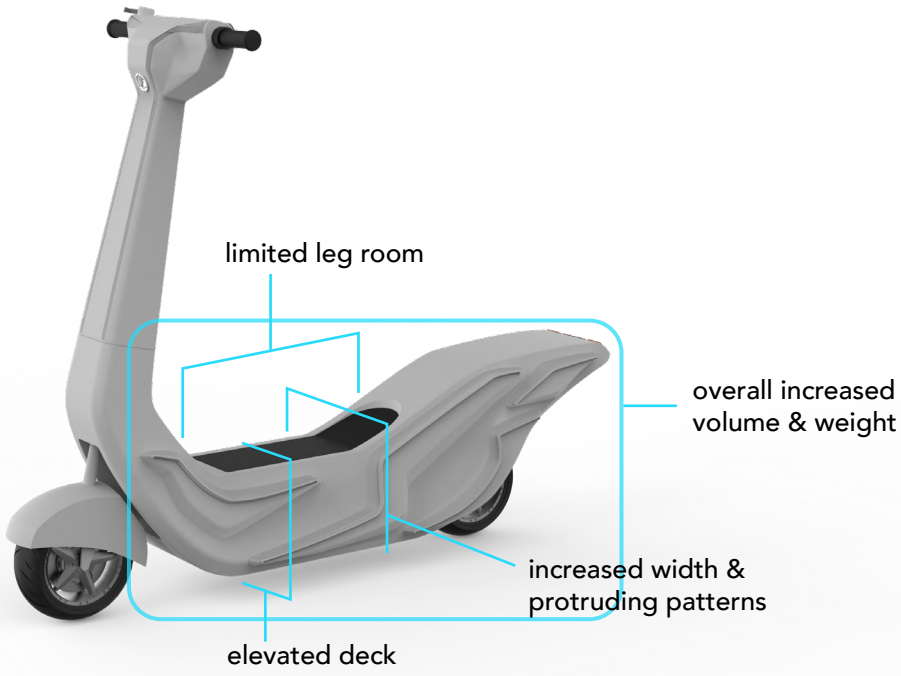


Figure 12.1: Aspects that concerns user experiences that are affected by the form.

influences multiple factors that concern the ergonomics and user experience (Figure 12.1). These factors are interrelated and jointly influence aspects such as the ease of mounting and dismounting, the riding posture, and overall riding comfort, which further affect riding safety. Moreover, the increased vehicle size and weight may reduce maneuverability, portability, and ease of storage, compromising key advantages of e-scooters. The dashboard, control interface, and handlebar were only developed conceptually to illustrate the integration of the communicative functions. Additionally, the increased number of control elements and communicative functions may be considered unnecessarily complex by people who prefer simplicity. Whether the proposed interface provides intuitive operation, sufficient reachability, and safe operation, and how they influence overall desirability remains uncertain.

Viability

The increased product complexity because of additional lighting components, larger housings, color scheme for countershading, and more demanding manufacturing and assembly processes is expected to increase production costs and, consequently, the market price. As a result, the viability of the design depends on whether the additional communicative features produce sufficient value to justify the increased costs.

From a commercial perspective, this is unlikely to be applicable for the current e-scooter market, where affordability and portability are primary considerations. In contrast, the proposed design may be more suitable for targeting premium consumer products, where users are more willing to pay for innovative functions, distinctive styling, and enhanced riding experiences. It may also provide value for shared mobility services, which may value factors such as user safety, riding experience, and public perception. If the intent-enhancing features are proven to reduce conflicts and improve safety in the long term, this value will strongly improve the product's market competitiveness and offset the additional costs. Additionally, one consideration is the rider's behavior. As the form transformation is activated under higher speed or acceleration, some users may deliberately accelerate or ride more aggressively to activate the lighting effect. Such unintended use could reduce the intended safety benefits and should therefore be taken into consideration in future development.

12.3 Limitations

12.3.1 Research

The identification of communication challenges and design opportunities was primarily based on secondary research. While this enabled the project to be grounded, it also means that the problem framing may not fully reflect contemporary e-scooter interactions. Although the proposed design is intended for European countries, interaction behaviors and regulations differ across countries. For example, literature describes e-scooters sharing lanes with pedestrians, cyclists, and motor vehicles in France (Tuncer & Brown, 2020), whereas traffic behavior in the Netherlands may be influenced by higher compliance with established traffic rules and more developed cycling infrastructure. RUs within the same traffic environment may have different expectations of e-scooter behavior due to differences in cultural background, travel experience, or familiarity with micromobility, such as international students or travelers. These nuances were not explicitly considered in the design and validation. In addition, there is a time lag in the literature, most of which reflects the condition several years ago. However, with the increased presence of e-scooters, the regulations are evolving and gradually being enforced, which may, in turn, lead to changes in the communication challenges in e-scooter interactions.

12.3.2 Formal language

One of the proposed intent communication strategies is influencing behavioral expectations through the vehicle form, which led to the definition of two contrasting form variations: the neutral base form and the high dominance (HD) form. Because of the selected transformation mechanism and the surface geometry, the patterns remain partially visible in the base form. As the patterns are intended to communicate speed and dominance, this might lead to the base form being perceived as more powerful than intended, and potentially reduce the distinction between the two form states. Furthermore, with the light elements, the HD form may be perceived as more aggressive or even intimidating. If so, this could not only create expectations that misalign with the actual behaviors, but may even reduce perceived safety. Additionally, the front and side views may convey different character qualities, potentially reducing the perceived coherence of the overall formal language. However, these remain hypotheses rather than validated findings. Perceptions of qualities such as softness, power, and aggression likely vary between individuals, and the project primarily investigated the transformation effect and evaluated whether the HD form can shift expectations relative to the base form, while how each form version is perceived individually and whether the formal language is perceived as coherent across different viewpoints remain under-researched, which requires dedicated user studies.

12.3.3 Product development

Although the design is intended to be realizable in the next few years, the outcome remains an early-stage product proposal, with several aspects requiring further specification, refinement, and validation.

In terms of functions, the speed and acceleration threshold to activate the form transformation was not defined, as it requires more empirical studies. The yielding and proceeding signals were only specified by moving direction and speed, while the detailed parameters of the animation pattern were not defined. The proceeding pattern was found to be ambiguous in intent expression during the user study, but it was not refined and re-evaluated within the timeframe of this project.

As the project primarily focused on the intent expression, the user experience and the ergonomics of the e-scooter were not investigated in depth. In particular, the size and geometry of the vehicle body might influence aspects such as the ease of mounting and dismounting, riding posture, and overall comfort, as well as riding safety. Similarly, the configuration of the dashboard, control interface, and handlebar were only developed conceptually. Although the layout considered the general placement and usage, and the individual control elements were adapted from existing designs in MMVs, the overall usability, including reachability, ease of operation, and distinguishability, was not evaluated. Consequently, how these aspects of usability, ergonomics, comfort, and how they eventually affect user experience, safety, and product desirability remain uncertain.

Furthermore, this project aimed to develop a practical product with the potential to be realized in the next few years, and it is considered to be feasible as it is based on the current e-scooter structure and existing technologies. However, for real-world production, engineering aspects such as electronics integration, structural design, and manufacturing were not developed within the scope of this project.

12.3.4 Validation

The form transformation of the final design was not tested and validated physically due to time and resource constraints. Because of the complexity of the geometry of the vehicle body, extra modifications needed to be made to the CAD model for 3D printing, and acquiring suitable lighting elements to produce the intended light effects for a scaled model presents further challenges. While the working principle was demonstrated by the experiments in the ideation phase, and the final effect was presented in digital renderings, they may not sufficiently simulate the effect in real-life, which is affected by multiple other factors such as light type and environmental conditions.

The user study also exhibited several limitations. First, the sample size of 20 is relatively small, which limited the statistical power of the study. A larger sample may provide a more reliable evaluation of the effectiveness of the signals. Second, rendered images and simplified animations presented in a static traffic context were used as the stimuli. While this enabled design variables to be controlled, it cannot fully replicate the perceptual complexity of real traffic interactions, where the light signals and other environmental cues, such as vehicle speed, relative distance, and other surrounding RUs, are present simultaneously. Therefore, how the presence of mixed visual cues affects the perception and interpretation of the proposed signals was not explored. Morevover, among the four safety-critical interaction scenariosidentified in the research phase, only one of them was included in the user study, which limits the generalizability of the findings. Whether form variations and explicit light signal support intent prediction in other scenarios remains uncertain.

Additionally, vehicle-based features intended to improve intent prediction through current state readability were developed based on visual analysis but were only partially validated. Particularly, the potential of the gaze lights to improve the steering direction clarity was demonstrated through lo-fi prototyping. However, how the integrated features contribute to overall speed and direction readability and whether they improve intent perception was not evaluated in realistic traffic scenarios.

In addition, the project targets mixed traffic environments, involving multiple types of RUs, including both VRUs (pedestrians, cyclists, other e-scooter riders) and motor vehicle drivers. Although the scenario mapping and viewpoint mapping took the variety of RUs into account, the validation study only addressed this by using an ambiguous scenario without specifying the observer's perspective. Using separate stimuli that represent the specific interaction scenarios involving different RU groups and perspectives will more accurately evaluate the signals' performance and how it might differ across interaction types.

Finally, the aim of the proposed design is to improve safety, but only the interpretation of signals was evaluated. While improved interpretation is an important prerequisite for safety, whether it leads to more appropriate or prompt reactions in these scenarios requires further evaluation.

Taken together, the maturity of both the engineering development and the functional validation indicate that the proposed design remains at approximately Technology Readiness Level (TRL) 3, where proof of concept has been demonstrated, but substantial engineering development and system-level validation are still required before practical implementation.

Figure 12.2: Technology Readiness Level.

12.4 Implications on Traffic Communication Strategy

The design development and findings from the user study generate transferable insights for future mobility design and research, especially involving MMVs, regarding how vehicle embodiment can support intent communication in mixed traffic environments.

12.4.1 Layered communication through vehicle embodiment

The proposed design demonstrated the potential of using form and light as two supplementary layers to support intent expression with implicit and explicit communication. Form variations were proven to influence behavioral expectations, and they showed potential in supporting intent perception in specific interaction scenarios, especially general encounters, although it has not been demonstrated. This also suggests that different communication strategies contribute differently to intent perception. This layered strategy opens up the design space for improving intent expression in traffic. Future mobility design could adopt a similar strategy of combining the visual transformation of the vehicle's form and light signals, or alternative approaches for different communication layers.

12.4.2 Establish distinct semantic associations

The user evaluation suggests that participants more frequently associated the proposed signals with existing traffic conventions than with the biological inspirations. This indicates that mental models related to traffic conventions or existing cues may provide a stronger semantic basis for signal design. In addition, the semantic association between different intents needs to be clearly separated to avoid ambiguous interpretations. Regarding this, biological inspirations may still be valuable to provide supplementary design features to strengthen the distinction between signals. This aligns with the three factors that contribute to successful communication of a signal in nature: detectability, discriminability, and memorability (Guilford & Dawkins, 1991, as cited in Oudshoorn et al., 2021).

- **Detectability**: the degree to which the signal is different from the environment and easy to perceive, which corresponds to salience.
- **Discriminability**: the degree to which the signal can be distinguished from other signals.
- **Memorability**: the degree to which the signal is memorable and can be associated with a certain action.

12.4.3 Introducing explicit cues strategically

The user study results showed that the addition of explicit signals slightly increased the perceived ease of interpretation regardless of whether the intent judgment was correct. This indicates that explicit signals can support intent perception by directing attention toward relevant communicative cues. Considering that implicit communication is often ambiguous, especially in complex interaction scenarios, introducing explicit cues strategically may provide clear intent expression. Future mobility design should therefore investigate and carefully consider what information needs to be conveyed, when explicit communication is required, and how salient it should be in critical interaction scenarios. This will ensure that explicit signals provide sufficient information clarity without creating visual clutter or increasing cognitive load.

12.4.4 Light as a communication channel and information

Although the light is intended as the means to achieve the form transformation, participants relied on it as a primary source of information for judging the behavioral expectation of the vehicle, and some interpreted it as a state of "ON". This indicates that lights can not only convey information through animation patterns, but also carry meaning with their presence in traffic contexts, which means light itself can be a multilayered communication mechanism. This nuance should be taken into consideration in the future design of light signals. More broadly, this implies that every visual cue, whether intentional or unintentional, can become an indicator of intent. Therefore, in future designs, all visual cues should be considered holistically regarding their potential communicative roles.

13 Recommendations

The recommendations are constructed according to their priority for future development. If additional development time were available, the first priority would be refining and validating the communication strategy, as these represent the core contribution of the proposed design and directly correspond to its objective of improving intent legibility. Subsequent work should be the refinement of other design aspects such as user experience and ergonomics, before proceeding to engineering development for implementation.

Communication Strategy Development

Refine current communication mechanism
- Establish clear proceeding and yielding signals
- Define the speed and acceleration threshold
- Optimize structural light color

Formal language
- Optimize visual coherence between two form states
- Align individual form state with intended expectations
- Validate transformation mechanism

Validation
- Validate the communicative functions in real-word scenarios
- Investigate the contribution of increased salience
- Evaluate influence on safety

Design Refinement

Product usability
- Evaluate and optimize ergonomics
- Optimize and validate the control interface

Reduce structural complexity
- Simplify body geometry
- Simplify overall housing design or explore foldable design

Engineering Developement

- Lighting implementation
- Vehicle engineering
- Ensure regulatory compliance

Additional Functions

- Explore communication of additional intents or altenative communication channels
- Explore automation functions

Figure 13.1: Summary of recommended future work with prioritization order (left to right).

13.1 Communication Strategy Development

13.1.1 Communication cues refinement

The primary refinement needed for the current design is the priority intent signals, as the proceeding signal was found to produce inconsistent interpretations. Based on the insights from the user study, refinement should focus on strengthening the semantic distinction between the two animation patterns by forming stronger associations with corresponding traffic-related cues. This may require further research into traffic conventions like signs, signals, and other visual cues, and exploring alternative animation characteristics, such as the use of pulsing versus flashing. Multiple signal concepts based on different association strategies could then be proposed and comparatively evaluated with users to identify the most effective solution. Once the most promising strategy has been established, the detailed animation parameters can be optimized through iterative user testing.

The speed and acceleration thresholds that activate the form transformation should also be defined. Future work could involve field studies, which investigate how road users' expectations and perceived safety change with different vehicle speeds and acceleration patterns across representative interaction scenarios. In addition, the form transformation could be gradual rather than binary, for instance, through progressive or sectional illumination. The activation logic could be informed by the study findings to ensure the perceived form aligns with behavioral expectations in different traffic contexts and further validated through user testing.

The visual characteristics of the structural lights could also be further explored. The current choice of cyan is a combined result of findings from eHMI research and design choice, and the light intensity was only specified qualitatively to ensure the intended visual effect without causing discomfort. Although most participants answered "lights" as the influencing factor on behavioral expectations, some also specifically mentioned the color, so it remains unclear to what extent the effects were contributed by the presence of lighting itself or by the color. Therefore, future research could investigate how different colors affect expectations and perceptions of their behavior. This could inform alternative color schemes that could potentially be implemented to increase the expressivity or offer more options for personalization for the riders.

13.1.2 Formal language

To further enhance the visual incoherence in the formal language and alignment with behavioral expectations, future studies should investigate how each form variation is perceived individually and evaluate the visual coherence of the overall design. Such studies should examine whether the base and HD forms communicate the intended behavioral characteristics and whether the formal language is consistent across viewing perspectives. Furthermore, the user study suggested that the changes in behavioral expectations were mainly influenced by the presence of lights rather than the visual change of form. Future work should therefore investigate the contributions of lighting and the 3D surface geometry by comparing alternative configurations, such as illumination without patterns, illuminated patterns on a flat surface, simplified 3D geometries, and the current design (Figure 13.2). These studies would help with understanding how each feature influences

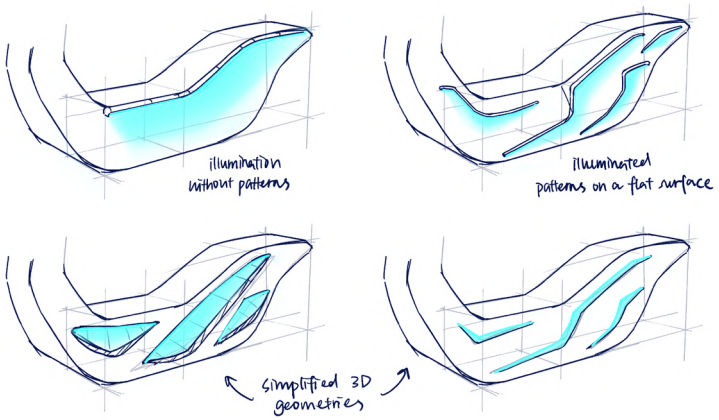


Figure 13.2: Potential configurations for further testing.

perceived behavioral expectations and affective qualities, informing subsequent refinement of the body patterns. The final selected transformation mechanism should be prototyped and tested physically to validate its performance under real-world lighting conditions.

13.1.3 Validation

Future validation should evaluate the integrated design in more diverse contexts and more realistic interaction scenarios with multiple dynamic cues being present simultaneously. In addition to explicit signals, studies should investigate how the vehicle-based features contribute to current state readability, including speed and steering direction, and whether they eventually support intent perception during interactions. The studies should also address the specific scenarios involving different road user types – pedestrians, cyclists, e-scooter riders, and drivers – and their specific viewpoints to examine how differences in experience, expectations, and perspectives influence signal interpretation. The studies should also address the specific scenarios involving different road user types – pedestrians, cyclists, e-scooter riders, and drivers – and their specific viewpoints to examine how differences in experience, expectations, and perspectives influence signal interpretation. Functional prototypes should first be assessed in controlled environments before being evaluated in immersive simulations.

Additionally, future research could investigate how the increased salience in the HD form influences predictability. Although the greater visual contrast of the HD form was originally intended to reinforce the expression of high dominance, it may also provide an additional benefit by further increasing the visual presence of the vehicle and leading to early detection. This is particularly relevant for the HD form, which represents behavioral characteristics involving higher speed, maneuverability, and a tendency to take priority. Further studies should therefore investigate whether the increased visual salience of the HD form facilitates early detection and whether this subsequently contributes to earlier anticipation and improved predictability of the vehicle.

Furthermore, the evaluation criteria should be more directly connected to the end goal of the design, which is improving traffic safety. Parameters such as reaction time, behavioral responses, and perceived safety should be assessed, which would provide stronger evidence of the effectiveness of the proposed communication strategy in real-world traffic contexts.

13.2 Design Refinement

13.2.1 Product usability

Design details relevant to user experience and usability should be further detailed and refined. In particular, the dashboard, handlebar, and control interface should be developed as an integrated design with the entire vehicle, while considering the interaction and ergonomic qualities. Particular attention should be given to the control interface, where the layout and operation of the controls should be tested using life-sized prototypes, focusing on ensuring intuitive operation and minimizing risks of mistaken or accidental activation. Future work should also explore the implementation of multimodal feedback, such as haptic or auditory confirmation when signals are activated. The concept should be iteratively refined through ergonomic analysis, prototyping, and user evaluation to achieve an optimal balance between intuitive operation, safety, and visual language. Furthermore, the riding posture, mounting and dismounting from the vehicle, parking, and general comfort should be evaluated and the design should be iterated if necessary to ensure that the redesigned form does not compromise usability.

13.2.2 Reducing structural complexity

Design refinement work should also aim to reduce the physical complexity of the product while maintaining its communication performance. A less complex housing design could also address the manufacturing challenges, reduced portability, and difficulty of storage.
Future work on refining the formal language can potentially support this goal by simplifying the body geometry without compromising behavioral expectations. If the recommended studies indicate that similar performance can be achieved with simpler geometries, the vehicle housing can be simplified accordingly. Reducing the structural complexity would reduce manufacturing complexity and assembly effort, improving the product's feasibility. This will, in turn, reduce overall production costs and potentially improve portability and storage as well, contributing to its viability. Conversely, if the surface geometry proves to be essential, future work should explore alternative strategies to simplify the housing, for instance, reducing the vehicle "tail". In parallel, additional structural design strategies such as a foldable structure or more compact designs to further improve its portability and ease of storage.

13.3 Engineering Development

To increase the TRL level and bring the proposed design closer to a manufacturable product, more detailed engineering development is required. Future work should specify the integration of lighting modules, electronics, wiring, and control systems, together with the overall structural design and assembly. Particularly, the lighting modules should be optimized to create the desired and robust illumination effect under different environmental conditions, while minimizing the power consumption. In addition, the remaining regulatory requirements should be addressed to ensure full compliance, including passive safety elements (e.g., reflectors), the steering mechanism, braking system, electrical and battery safety, footrest design, and overall vehicle dimensions before implementation.

13.4 Additional Functions

13.4.1 Additional communication cues

Beyond the current concept, future work could explore extending the communication system to express additional intent-related information. In particular, speed and trajectory change were identified as critical intents for improving the predictability of the vehicle's movement. During ideation, a light band along the upper edge of the vehicle body was proposed to communicate these intents, but the concept was later discontinued due to increased visual complexity. Further refinement of the design could revisit this idea and investigate how these intents can be expressed more subtly while maintaining communication clarity.

In addition to intents, future work could also investigate alternative communication channels. Although projection-based signaling was found to be ineffective under bright daylight conditions and was therefore excluded from the final design, the precedent research and ideation demonstrated its potential. It can be explored as a supplementary communication channel to strengthen existing signals or express additional intent where appropriate.

13.4.2 Automation functions

Beyond the current concept, future work could explore extending the communication system to express additional intent-related information. In

particular, speed and trajectory change were identified as critical intents for improving the predictability of the vehicle's movement. During ideation, a light band along the upper edge of the vehicle body was proposed to communicate these intents, but the concept was later discontinued due to increased visual complexity. Further refinement of the design could revisit this idea and investigate how these intents can be expressed more subtly while maintaining communication clarity.

In addition to intents, future work could also investigate alternative communication channels. Although projection-based signaling was found to be ineffective under bright daylight conditions and was therefore excluded from the final design, the precedent research and ideation demonstrated its potential. It can be explored as a supplementary communication channel to strengthen existing signals or express additional intent where appropriate.

14 Conclusion

This project followed a research through design process to investigate how the physical embodiment of an e-scooter can enhance the legibility of vehicle intent in traffic interactions. A literature review and interaction analysis identified critical intents in key interaction scenarios, and precedent research provided a theoretical basis and inspiration that informed the iterative design exploration. The final outcome is a proposed e-scooter design that integrates form features and dynamic lighting to support intent legibility, with the aim of improving both objective and perceived safety for the rider and surrounding road users in mixed urban traffic. Formal design, including vehicle-based features and two form variations, shapes behavioral expectations of the vehicle, while light signals provide explicit intent communication in critical interaction scenarios and act as part of the formal features, jointly contributing to the intent legibility of the e-scooter. The communicative features and cues were designed based on existing perceptual associations and mental models. A user study evaluated the form transformation and priority signals. The results suggested that visual form transformation successfully influenced behavioral expectations in the intended direction. The priority signals showed potential for supporting intent interpretation during priority negotiations, although the proceeding signal produced inconsistent interpretations, which require further refinement. The design demonstrated its potential for further development and implementation as a feasible next-generation mobility product. Future work should focus on refining the communication strategies and ensuring usability before proceeding to detailed engineering development.
Beyond the proposed design itself, the proposed multi-layer communication strategy and the design knowledge generated through this project contribute to future research and design of MMVs or the broader mobility field, informing how vehicle embodiment can support predictability and intent communication in traffic.

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Appendices

Appendix 1: Project Proposal

Project Proposal form

IDE Master Graduation Project

In this proposal the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document needs to be prepared for the Kick-off meeting and should be submitted in MyCase.

Name student Jiani Yang **Student number** 6236413

Project title A Micromobility Vehicle Design with Enhanced Behavioral Legibility

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

MSc programme ☐ Design for Interaction ■ Integrated Product Design ☐ Strategic Product Design

☐ Other *(in case of a double degree outside IDE):* _____

Introduction

Describe the context of your project in the box below; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Micromobility vehicles (MMVs) - lightweight vehicles such as (e-)bicycles and (e-)scooters have emerged as an increasingly prominent inner-city transportation mode as they facilitate short-distance commutes and first- and last-mile connections to public transport. They are expected to constitute a substantial part of future traffic systems.
However, their growing presence raises safety concerns, particularly concerning vulnerable road users due to their lack of protection, including MMV users themselves and pedestrians. Research suggests that many safety-critical events resulted from interaction with another road user. Crashes with motor vehicles were the most frequent circumstance among MMV injury events, and often result in more severe injuries. While collisions with pedestrians account for a smaller proportion of accidents, they can still result in serious injuries, and near accidents occur considerably more frequently than collisions. Many studies further indicate that such safety-critical events occur more often in shared spaces between different types of road users. In many urban environments, MMVs often share lanes with pedestrians, which further increases interaction frequency, leading to higher safety risks.
Safe traffic interactions rely on correct anticipation of each other's behavior, which is inferred from various cues. When the communication between interacting road users is problematic, leading to such cues being absent, ambiguous, or misinterpreted, road users may form incorrect expectations about others' actions, reducing both their objective and perceived safety.
The main stakeholders are the MMV users and all the interacting road users (pedestrians, drivers). Improving behavioral and intent clarity emerges as an opportunity to form safer and more predictable interactions between road users.

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Introduction (continued): space for images

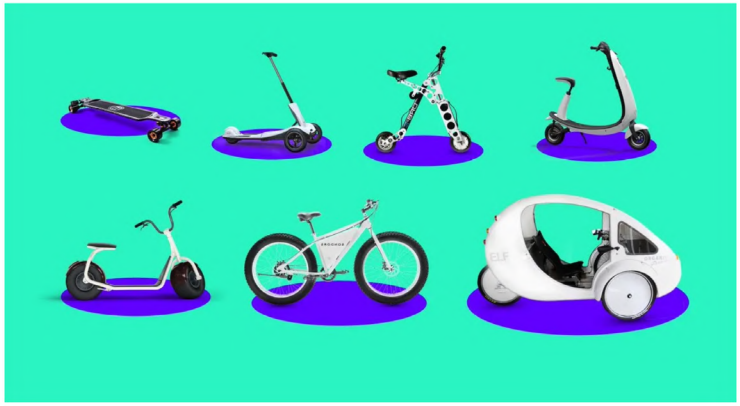


Figure 1: Lopez, G. H. J. (2019). Future micromobility designs. Medium. https://medium.datadriveninvestor.com/micromobility-is-the-future-of-vehicles-220c2c0c9b0

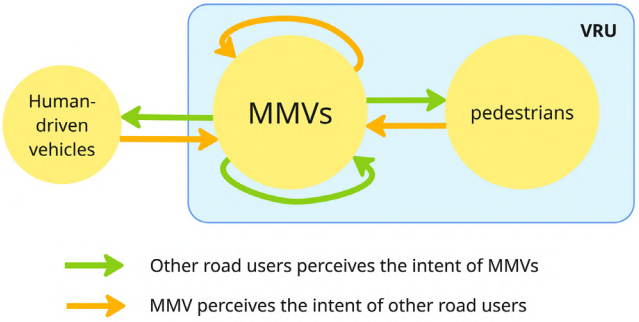


Figure 2: Perception of intent and actions between MMV and surrounding road users

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice. (max 200 words)

In mixed urban traffic environments, interactions between MMV users and other road users frequently experience uncertainty about each other's presence, intentions, and future actions, especially involving unfamiliar MMV types such as e-scooters. Due to the maneuver flexibility of MMVs, limited vehicle-based signaling, shared use of space with pedestrians, and variability in human behavior, safety-critical information is often absent, ambiguous, or misinterpreted. As a result, both MMV users and interacting road users may misjudge situations or fail to respond in time, increasing risks and reducing perceived safety.

While these challenges arise from multi-level causes, this project targets vehicle-level factors to ensure tangible and controllable intervention within the scope of a product design project, focusing on how vehicle embodiment can support its behavioral predictability and legibility. It explores how existing cues (e.g., speed change, posture, trajectory) can be clarified or complemented through integrated embodied signaling strategies, including form, movement expression, and dynamic elements such as light or sound.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project (1 sentence. As you graduate as an industrial design engineer, your assignment will start with a verb (Investigate/Design/Validate/Create), and you may use the format:
(Investigate/Design/Validate/Create) ***a*** *(what will be the deliverable → prototype/roadmap/process/ intervention /approach/guideline/strategy/…)* ***to*** *(what should it do →(create/understand/evaluate/validate/ improve/execute/ analyse/…) (the objective → experience/value/process/product/…)* ***for*** *(whom → target group/client/…)* ***in*** *(what context).*

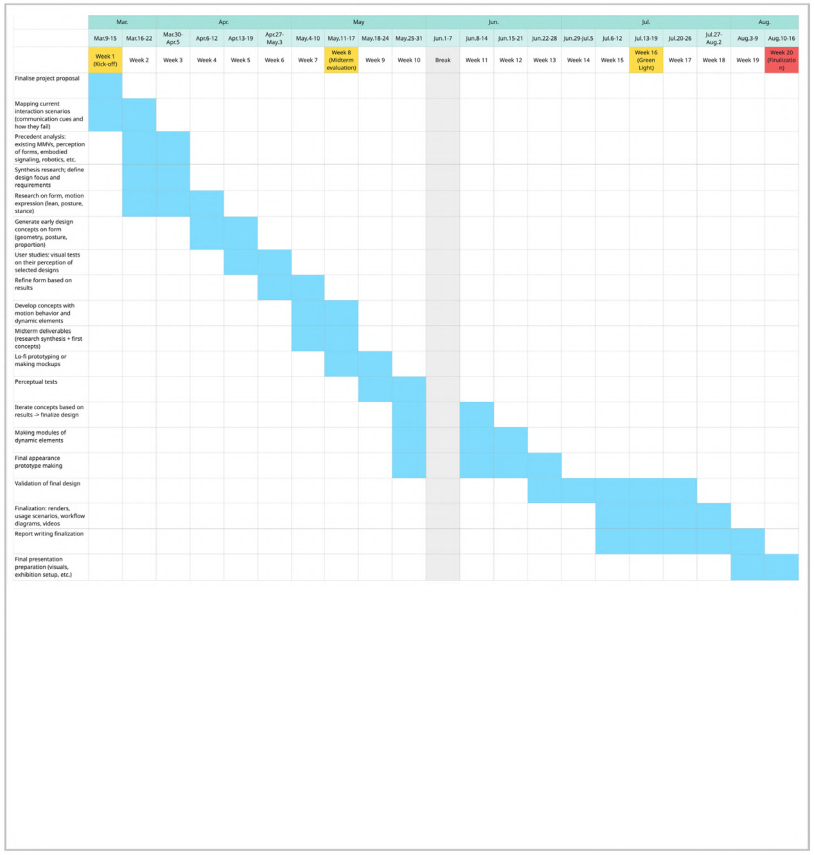
Design an MMV prototype with improved behavioral predictability and legibility through vehicle embodiment to reduce interaction uncertainty for other road users in traffic interactions.

Explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words).

The project begins with a literature review to examine existing cues for intent communication, challenges in MMV interactions, and underlying causes to identify where design intervention may add value. Then, key interaction scenarios will be mapped to analyze how cues break down in the expression and perception of relevant intents and identify design opportunities for enhanced legibility. A precedent analysis of existing MMVs and related signaling systems will inform potential embodiment and signaling strategies.
Building on these insights, design concepts will be generated through ideation, iterative sketching, 3D modeling, and prototyping. Early design concepts will be evaluated through controlled user testing in simulated traffic contexts using lo-fi prototypes, mock-ups, or digital simulations, and the selected designs will be prototyped as functional modules. An appearance prototype will be fabricated in parallel, demonstrating the form and function aspects of the final design together with the functional modules.

Project planning

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include the ***Kick-off***, ***Midterm Evaluation***, ***Green Light*** *and* ***Finalisation*** *(ceremony). Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities). Add (an image of) the planning in the box below. If it is not readable, you can add the planning as an attachment to My Case along with this Proposal.*



Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some (max 5) personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology (200 words max).

My experiences in living in busy major cities have made me aware of the emerging urban mobility issues, and I have been driven to find solutions through technology-driven and user-centered design. This topic offers me the opportunity to explore the mobility field, and aligns with my ambition to create impactful designs that improve urban living conditions, enhance commuting experience, and contribute to a more sustainable and resilient future.

In the graduation project, I hope to gain more experience in investigating and designing for a real-world challenge, and work on a tangible product, including technological integration, product materialization, and validation. Additionally, I want to enhance my ability of making informed design decisions throughout an individual project.

Appendix 2: Evaluation of Signaling Approaches

Table: Evaluation of eHMI designs

	Pros	Cons
Light patterns (LED)	• High visibility • Widely applied (mental models) - easy to interpret • Widely researched (different parameters) • Suitable for embodiment	• May have a limited number of meanings • May require learning
Projection	• Effective in conveying spatial information • Can extend the display outside the vehicle body • Less prone to vertical occlusion	• High hardware requirement • High energy consumption • Limited readability in complex scenarios • Sensitive to lighting conditions
Text	• High information clarity and variability	• Low readability from a distance • Low readability at a high speed • Prone to language barriers
Icons	• No language skills necessary	• Low readability from a distance • Low readability at a high speed • May require learning
Acoustic - sound patterns	• Effective in signaling presence • No language skills necessary	• The e-scooter may not be recognized as the sender • Difficult to map meanings to patterns • Prone to ambient noise
Acoustic - spoken words	• High information clarity and variability	• The e-scooter may not be recognized as the sender • Prone to language barriers • Prone to ambient noise

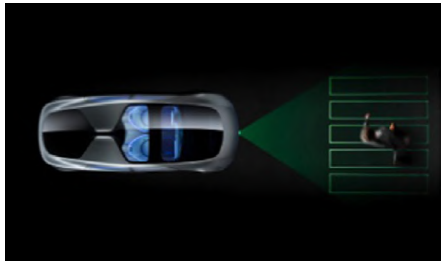


Figure 15.1: eHMI using a projected crosswalk.

Among projection-based approaches, some eHMI designs use projected crosswalks. But such designs require large projection space, which, in turn, requires more complext hardware, and are therefore considered not suitable for e-scooter applications. Projection-based approaches in this project focuses on simple and abstract patterns.

Figure 15.2: Examples of text-based eHMI designs.

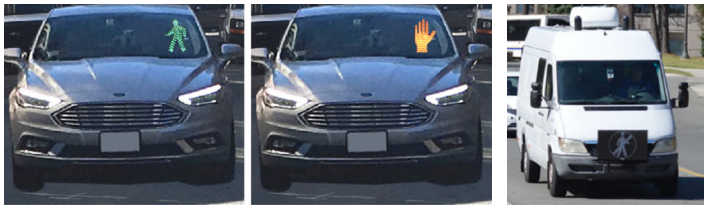


Figure 15.3: Examples of icon-based eHMI designs.

Figure 15.4: Examples of anthropmorphic eHMI designs.

Particularly, anthropmorphic designs is another common approach in eHMIs, which use human-like elements or human characteristics for communication. However, there appears to be no agreement on the usefulness of anthropomorphic eHMIs (Tabone et al., 2021, as cited in Oudshoorn et al., 2021). Moreover, as the e-scooter rider is visible, human-embodied cues are still present, therefore it is considered less appropriate to adopt human-like cues on the vehicle.

Appendix 3: MMV Visual Analysis

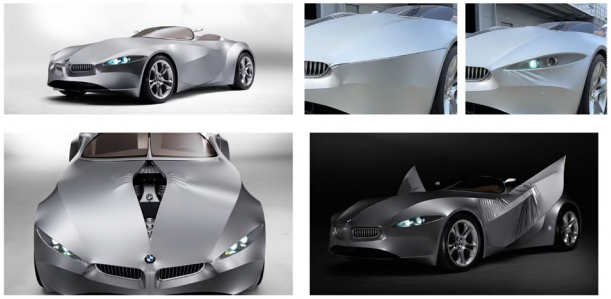
Table: Analysis of expected movement characteristics, readability of key states, and contributing features in each MMV type

		bicycle	fat-bike	moped scooter	mobility scooter	e-scooter	segway	skateboard
Speed	level	medium	medium-high	high	low	medium-low	medium-low	medium-low
	features	• large and thin wheels (+) • leaning posture (+) • manually powered (-)	• relatively wide wheels • electric assisted • motorized vehicle association	• large size • electric assisted • motorized vehicle association	• large mass • electrically • typically elder user group	• tiny wheels • small size • standing posture • electric assistance less visible	• inline wheel configuration • standing posture	• small size • standing posture • manually powered
Maneuver ability	level	medium	medium-high	medium	low	high	high	high
	features	• large wheels (-) • thin wheels and frame (+)	• relatively small wheels (compared to regular bicycles)	• relatively small wheels (+) • inline wheel configuration (-) • relatively large mass (-)	• large mass • four wheel configuration • squared, large footprint • seated posture	• slim profile • small wheels • inline wheel configuration • upright posture • narrow base	• upright posture • side-by-side wheel configuration • narrow base	• small size • small wheels • no front/back distinction • upright posture
Directionality	level	high	high	high	high	medium-low	low	low
	features	• large wheels • in-line wheel configuration • elongated frame	• in-line wheel configuration • elongated body with clear front	• in-line wheel configuration • elongated body with clear front	• four wheel configuration • clear front	• unclear front (-) • inline wheels (+) • upright posture (–)	• side-by-side wheel configuration • upright posture	• tiny wheels • four-wheel configuration • no clear front
Speed legibility	level	high	medium	medium-low	high	low	low	medium-high
	features	• visible pedalling and wheel rolling • leaning posture (mountain bikes)	• visible wheel motion (+) • less visible rider action (-)	• less visible wheel motion • no visible rider action • (break lights)	• typically slow movement • large mass	• electric powered • low visibility of wheel motion • no visible propulsion	• no visible rider action	• visible pushing action (+)

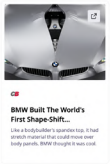
Appendix 4: Research and Ideation on Physical Transformation

Shape-shifting cars

BMW GINA



- By using the aluminum mesh with its moveable electro-mechanical parts on the outer body of his concept car, he could play with the surface of his car. Making it wider, or higher (at the tail, where the spoiler would rise at high speed for extra downforce). Or, as with the hood, it would open straight down the center line, to give access to the engine.
- At the front, the spandex covered the headlights when they were not in use. If you switch on the lights, the material would slide to the sides. At the back, the brake lights simply shone through the material. The same applied to the grille - the spandex would cover it when stationary, and slide sideways from the center line outwards to open up the grille when you started driving.



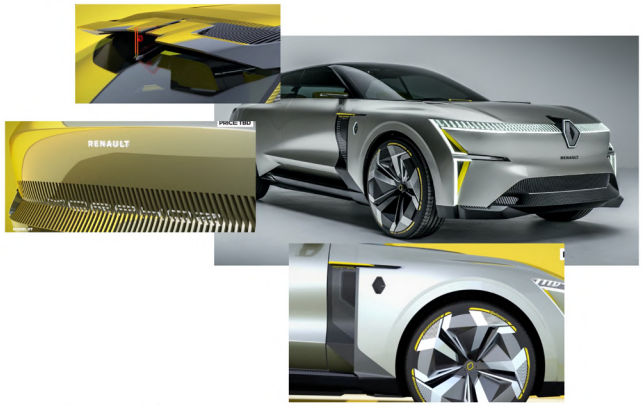
Mercedes-Benz Vision AVTR

Their energy supply is provided by the cached current of the integrated solar plates on the back of the VISION AVTR. The 33 multi-directionally movable surface elements act as "bionic flaps".

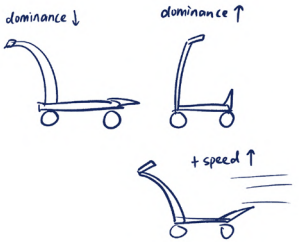
Triggo

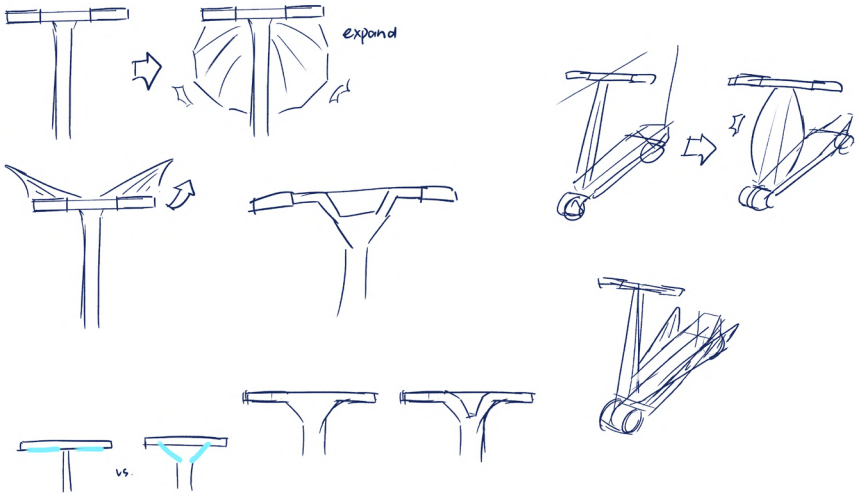
It can shrink into a nimble sports car for performance driving, or stretching into a luxiorious grand tourer for comfort and cruising => changes the dynamics and personality of the vehicle

Renault Morphoz



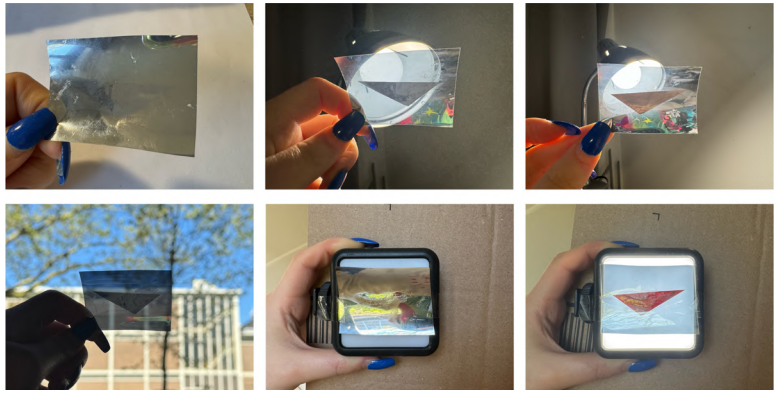
Damon Hypersport





Changing the perceived character and expressing non-yielding intent through physical transformation of the vehicle has also been explored through sketches and research on precedents of shapeshifting vehicles. These were mainly intended to broaden the idea space. This direction was not continued because of practical considerations.

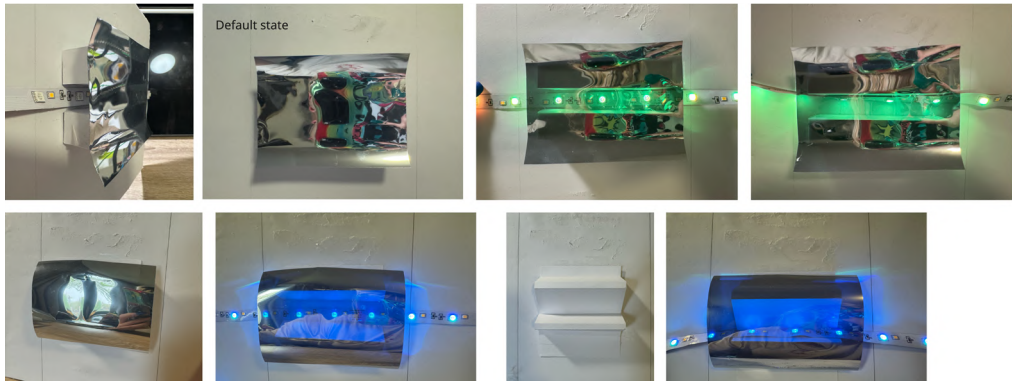
Appendix 5: Experiments on Layered Structure with Mirror Film



2D pattern

The effect is evident when the background light intensity increases, when the light is both from a distance and attached, and the pattern is easily controllable.

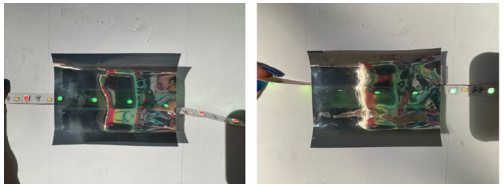
Regular indoor lighting



3D pattern with different internal structures

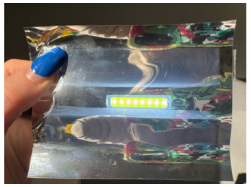
Under medium-intensity ambient light, in the default state, the patterns are completely invisible. When the lights are on, they produced evident effect with the pattern revealing internally under the mirror film.

High intensity lighting (sunlight) conditions



Using the same LED strip (highest brightness) as the structural light, only the shape of the LED can be revealed.

high intensity flashlight



When the added light intensity is high, the effect is still significantly impaired.

LED panel

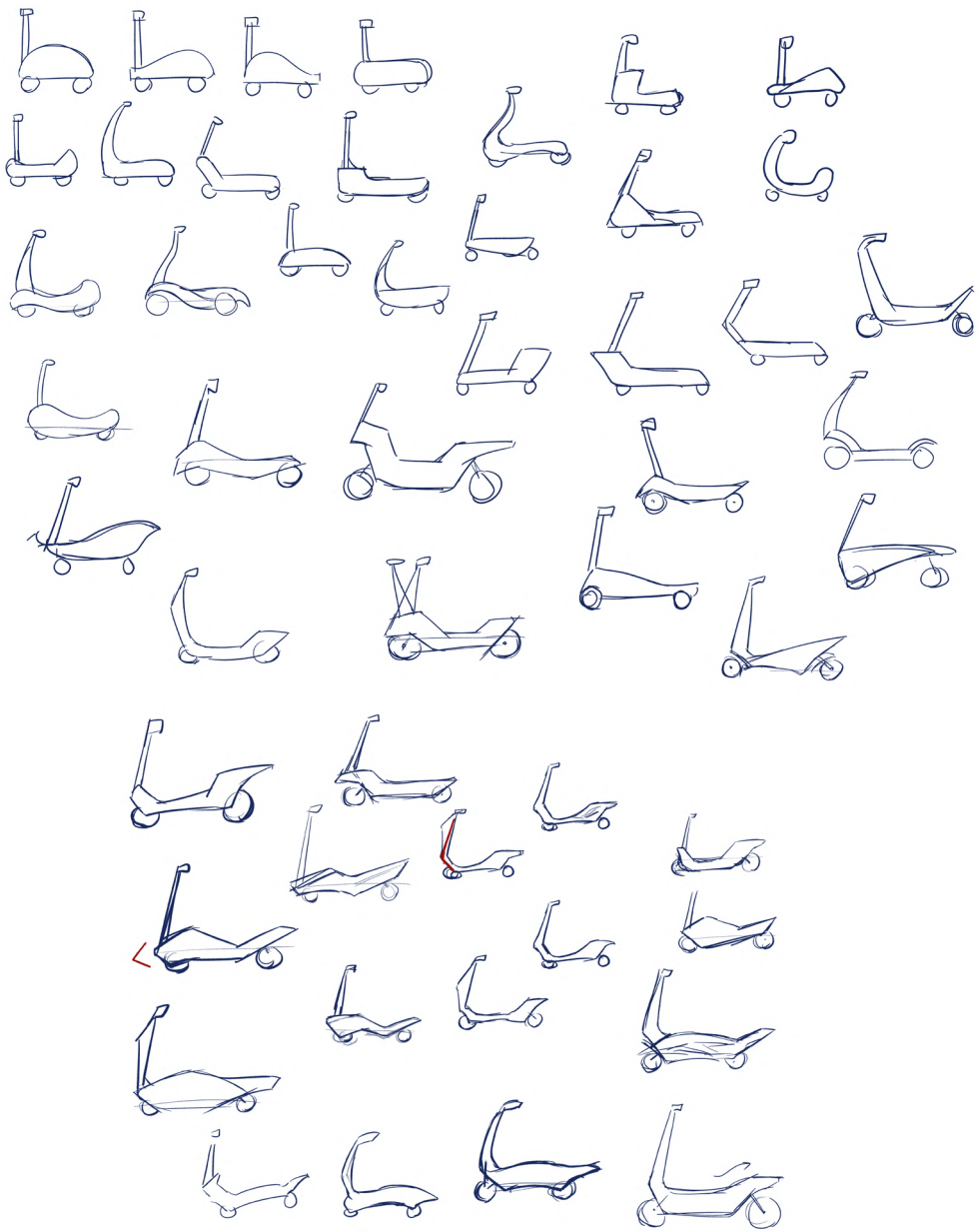
Only with a consistent surface light, the distinction between sections can be clear.

Regular indoor lighting

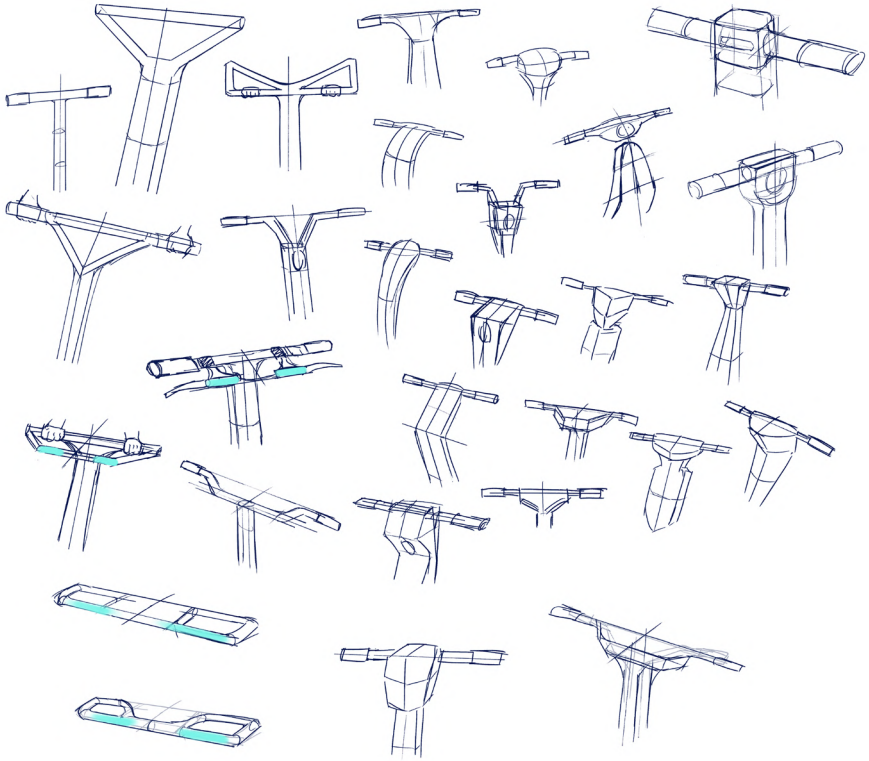
Applying mirror film to only the patterns

Since the shape of the pattern is already visible in the default state, the light only has a coloring effect, so the change is less evident and expressive.

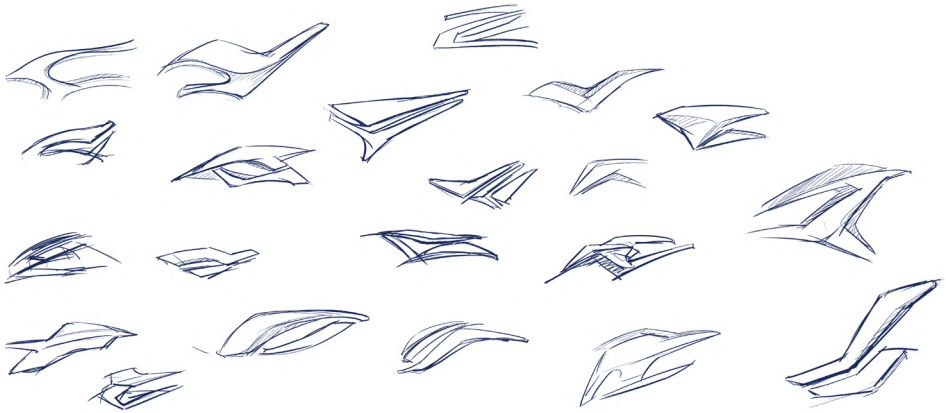
Appendix 6: Preliminary Form Exploration



Sketches that explored the vehicle form informed by the precedent research.



Sketches to explore different designs of the vehicle front.



Sketches of patterns in high dominance designs.

Appendix 7: Questionnaire of the User Study

E-Scooter Intent Perception

You are being invited to participate in a research study as part of an MSc graduation project on how the intent of an e-scooter is perceived by interacting road users.

In this study, you will be asked to observe different e-scooter designs and indicate how you interpret their intentions (such as speed change, trajectory change, yielding/passing) in different traffic scenarios. A small number of optional open-ended questions will also be included.

The study will take approximately 10 minutes to complete. This study is anonymous and no personally identifiable information will be collected. The results will be used solely for academic research purposes and may be included in a publicly accessible master's thesis.

Some participants may experience minor fatigue or discomfort from viewing visual stimuli.

Your participation in this study is entirely voluntary, and you are free to take breaks, omit any questions, or withdraw at any point. Note that responses cannot be withdrawn after submission as this is an anonymous survey.
If you have any questions about this study, please contact: Jiani Yang - j.yang@student.tudelft.nl

By proceeding to the survey, you indicate that you have read and understood the information above and agree to participate in this study.

* Required

General behavioral expectations

Imagine that you encounter the following e-scooters on the road. For each image pair, please select the option (A or B) that best answers the question.

There are 6 image pairs under each question, so please make sure you have made all the selections before proceeding to the next question.
The choice should be made **based on your first impression.**

1

Question 1: Which scooter looks more likely to move at a high speed?

2

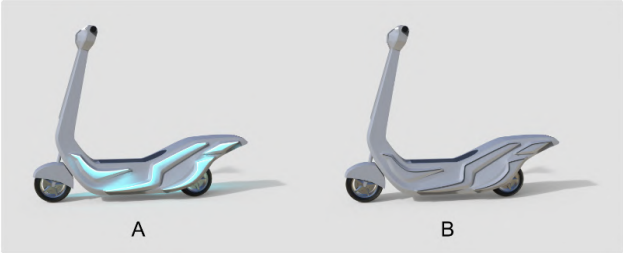
Q1_F2 *

- A
- B

Q1_R1 *

- A
- B

Q1_S2 *



- A
- B

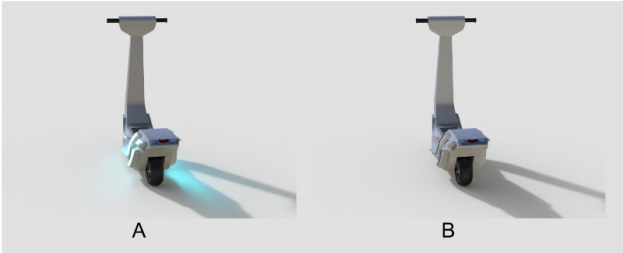
Q1_F1 *

- A
- B

Q1_S1 *

- A
- B

Q1_R2 *



- A
- B

8

Question 2: Which scooter looks more likely to make **sudden acceleration** or **direction changes** while moving?

9

Q2_S1 *

- A
- B

10

Q2_F2 *

- A
- B

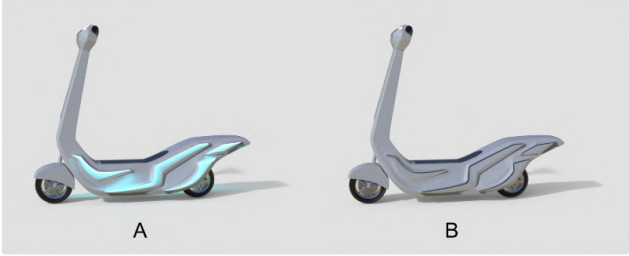
11

Q2_R2 *

- A
- B

12

Q2_S2 *



- A
- B

13

Q2_R1 *

- A
- B

14

Q2_F1 *

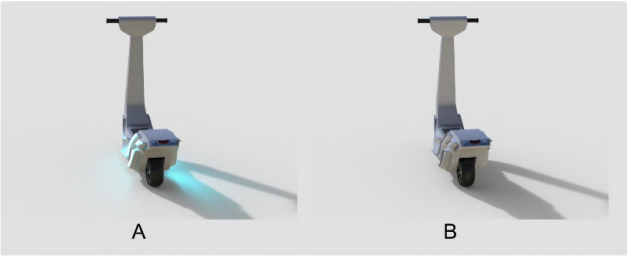
- A
- B

15

Question 3: Which scooter looks **more likely to proceed rather than give way** when encountering another road user?

16

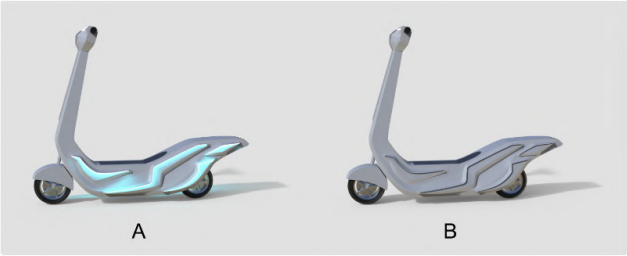
Q3_R2 *



- A
- B

17

Q3_S2 *



- A
- B

18

Q3_F1 *

- A
- B

19

Q3_R1 *

- A
- B

20

Q3_F2 *

- A
- B

21

Q3_S1 *

- A
- B

22

What factors/visual features influenced your choices most in this section?

Crossing encounters

Imagine that you are approaching an unsignalized crossing and are about to cross the road (in the direction indicated by the arrow). An e-scooter is approaching from another direction, and **its path will intersect with yours**. For each image/video, observe the e-scooter and answer the following questions based on this context.

23

Scenario 1

24

(1-1) What do you think the e-scooter is about to do next? *

- ◯ Yield and let you go first
- ◯ Take priority and proceed before you

29

(2-2) How confident are you with this judgment? (1 = not confident at all, 7 = extremely confident) *

	1	2	3	4	5	6	7
Confidence	◯	◯	◯	◯	◯	◯	◯

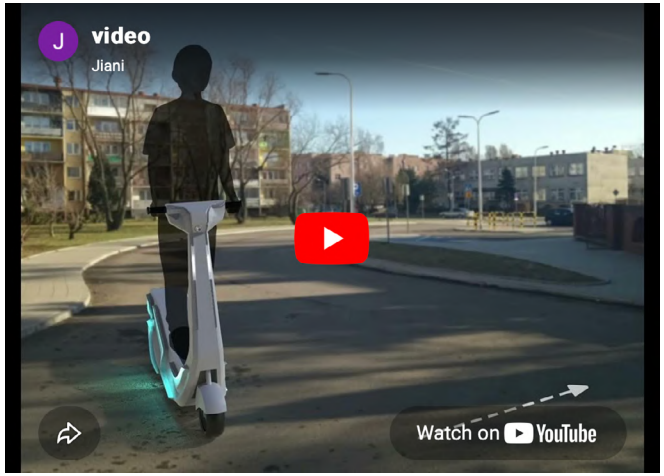
30

(2-3) How easy was it to understand what the e-scooter intended to do? (1 =extremely difficult, 7 = extremely easy) *

	1	2	3	4	5	6	7
Ease of interpretation	◯	◯	◯	◯	◯	◯	◯

27

Scenario 2



28

(2-1) What do you think the e-scooter is about to do next? *

- ◯ Yield and let you go first
- ◯ Take priority and proceed before you

29

(2-2) How confident are you with this judgment? (1 = not confident at all, 7 = extremely confident) *

	1	2	3	4	5	6	7
Confidence	◯	◯	◯	◯	◯	◯	◯

30

(2-3) How easy was it to understand what the e-scooter intended to do? (1 =extremely difficult, 7 = extremely easy) *

	1	2	3	4	5	6	7
Ease of interpretation	◯	◯	◯	◯	◯	◯	◯

31

Scenario 3

32

(3-1) What do you think the e-scooter is about to do next? *

- ◯ Yield and let you go first
- ◯ Take priority and proceed before you

33

(3-2) How confident are you with this judgment? (1 = not confident at all, 7 = extremely confident) *

	1	2	3	4	5	6	7
Confidence	◯	◯	◯	◯	◯	◯	◯

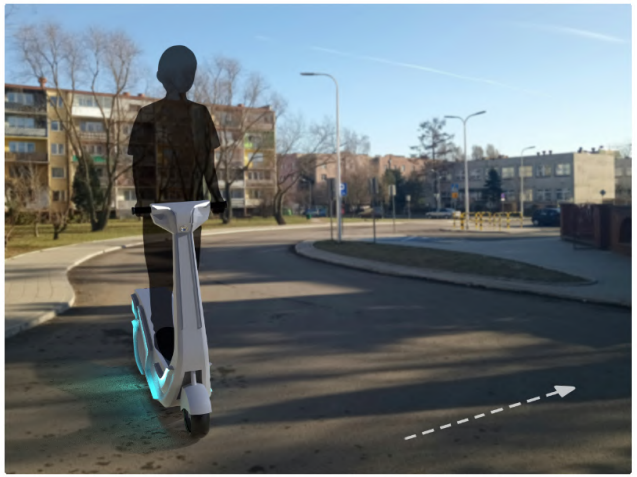
34

(3-3) How easy was it to understand what the e-scooter intended to do? (1 =extremely difficult, 7 = extremely easy) *

	1	2	3	4	5	6	7
Ease of interpretation	◯	◯	◯	◯	◯	◯	◯

35

Scenario 4



36

(4-1) What do you think the e-scooter is about to do next? *

- ◯ Yield and let you go first
- ◯ Take priority and proceed before you

37

(4-2) How confident are you with this judgment? (1 = not confident at all, 7 = extremely confident) *

	1	2	3	4	5	6	7
Confidence	◯	◯	◯	◯	◯	◯	◯

38

(4-3) How easy was it to understand what the e-scooter intended to do? (1 =extremely difficult, 7 = extremely easy) *

	1	2	3	4	5	6	7
Ease of interpretation	◯	◯	◯	◯	◯	◯	◯

39

Scenario 5

40

(5-1) What do you think the e-scooter is about to do next? *

- ◯ Yield and let you go first
- ◯ Take priority and proceed before you

41

(5-2) How confident are you with this judgment? (1 = not confident at all, 7 = extremely confident) *

	1	2	3	4	5	6	7
Confidence	◯	◯	◯	◯	◯	◯	◯

42

(5-3) How easy was it to understand what the e-scooter intended to do? (1 =extremely difficult, 7 = extremely easy) *

	1	2	3	4	5	6	7
Ease of interpretation	◯	◯	◯	◯	◯	◯	◯

43

What factors/visual cues influenced your judgment most in this section?