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# **Material Perception in Alternative Fuel Car Interiors. Increasing Marketability through Green Design Cues.**

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## **Summary**

As the market penetration of alternative fuel vehicles is still uncertain, defining green design cues for their design is of specific relevance to target environmentally conscious customers. This paper is a review of the existing literature aiming at summarizing the market penetration scenarios of alternative fuel vehicles over the next years, consumer demand for sustainable materials, and present methodologies to represent characteristics of eco-friendly mobility in the interior of alternative fuel vehicles. In particular, present attempts to correlate materials with green design cues are explored. Finally, projections for the future of the field are suggested, posing enchanting research questions to further unify the field of environmentally conscious design with the domain of product personality.

*Keywords: consumers, demand, passenger car, sustainability*

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## **1 Purpose**

### **1.1 Product Personality and Sustainable Materials to Target Customer Satisfaction**

Design cues describe choices for design aspects that follow a specific aesthetic language to guide the design of a product [1]. Their definition involves chosen colours, shapes, patterns, textures, layouts, and materials. The defined aesthetics evoke associations, which are referred to as the things the product reminds the observer of. Moreover, perceptions represent the reactions the product induces on the consumer, and they describe the way the product makes the user feel. The ensemble of product aesthetics, product-driven associations, and consumer perceptions refers to product personality. While product personality and -usability define the psychological side of a product, the materials and processes used to manufacture it represent product physiology; according to the specified context (i.e. who? where? when? why?), these two parts melt together to successfully fulfil the requirements of functionality, usability, and customer satisfaction. [2].

Given the huge uncertainty regarding the future orientation of sustainable passenger mobility, a user-centred design approach is key to target consumer acceptance of alternative fuel vehicles (AFVs). AFVs are vehicles that run on a single fuel source other than traditional petroleum fuels, e.g. battery electric- (BEVs), fuel cell electric- (FCEVs), natural (including liquefied and compressed versions) gas- (NGVs), bio (including bioalcohol and ethanol, biogas, and biodiesel versions) fuel- (BVs), and compressed air- (CAVs) vehicles. In addition, AFVs refer to cars running with any multiple fuel source technology that does not involve solely petroleum, e.g. flexible fuel- (FFVs), hybrid electric- (HEVs), and plug-in hybrid electric- (PHEVs) vehicles. As environmental issues and social responsibility are becoming important to consumers [3], developing

design cues that communicate the *look* and *feel* of sustainability to design AFVs may be an appealing strategy to target environment-conscious customers.

The selection of sustainable materials for car interior can play an important role in the definition of a multisensory experience in the vehicle since passengers can vision, touch, and smell them. The working definition of sustainable material used throughout this paper is *a material that is intentionally and methodically designed to lower the environmental impact versus the status quo, be that by the adoption of natural renewable fibres or recyclates, using a scientifically-based environmental impact assessment tool (e.g. LCA) of the designer's choosing*. Implementing *green* design cues through eco-friendly materials may be of specific interest to target product-driven associations and consumer perceptions, thus increasing the marketability of AFVs, Fig. 1.

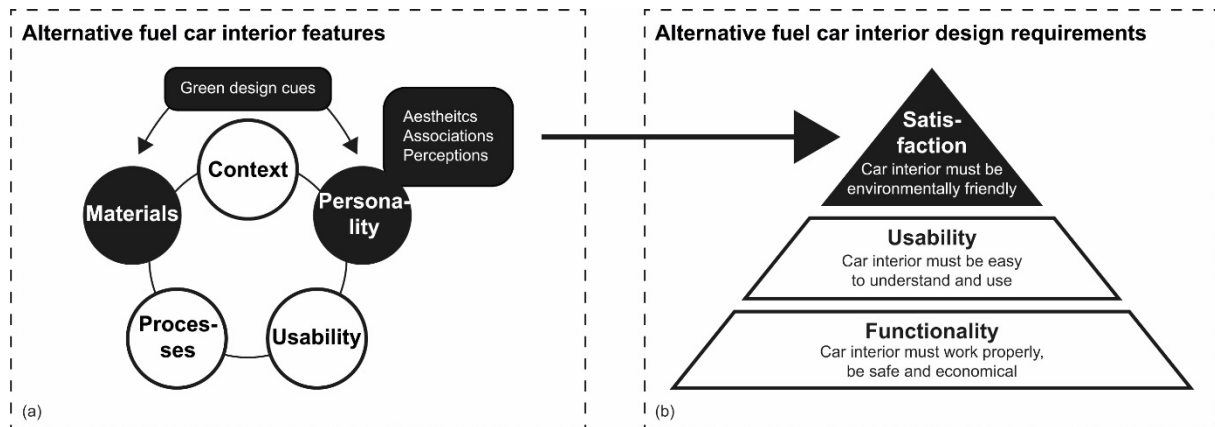


Figure1: Flow diagram based on [2] showing how (a) the correlation between chosen materials and product personality features defines green design cues to target (b) environment-conscious customer in product design, as focus of this article

## 1.2 Challenges and Research Questions

Four main obstacles challenge the successful unification of the field of environmentally conscious design with the domain of product personality in the design of AFVs. The first uncertainty is related to present low market penetration of AFVs and the effective perception of the social value associated with owning an AFV. This obstacle leads to the following research question:

- *What is the customer demand for environmentally friendly vehicles?*

The second barrier involves the possibility for customers to actually *see* eco-friendly materials in car interior. Despite the increased interest of the automotive industry on sustainable consumption, most of interior and exterior car parts made of recyclates and natural materials are invisible to customers and hence integrated in the car without their knowledge. Consequently:

- *What is the customer demand for environmentally friendly materials in car interior?*

Moreover, as car interior involves a variety of interfaces and items to guarantee human vehicle interaction, it is of specific relevance to understand what items are key to contribute to overall customer multisensory experience. Hence:

- *What are the key car interior components contributing to consumer perception?*

The fourth obstacle regards the successful targeting of environment-conscious customers, e.g. customer recognition of design cues representing environmental friendliness. While specific design cues can be implemented for representing characteristics such as aggressiveness or childishness in a product [4], research contributions on design cues that are socially accepted and recognized as being *green* are missing. This challenge gives rise to further two research questions:

- *How can car designers target the demand of environment-conscious customers in the design process?*
- *How can product personality represent environmentally friendly materials?*

To face these topics, the remainder of this paper is divided into four sections. Section 2 describes the research method used to examine the literature, including specific variables and topics that were assessed; section 3 presents the findings for each selected topic; section 4 highlights the implications of the findings, providing projections for future AFVs design. This review can have an important role in the development and diffusion of shared visions about the future design of AFVs, thus creating powerful expectations of the environmental, social, and economic potential of product personality. Moreover, it can mobilize the intellectual, financial, political and institutional resources necessary to increase the marketability of these vehicles.

## 2 Approach

A wide systematic scan of journals and conference databases was carried out, searching both papers and conference proceedings. The following databases were used: Engineering Village, Google Scholar, IEEE Xplore, OECD-iLibrary, Science Direct, SpringerLink, Web of Science, and Wiley Online Library. More than 150 studies were found, excluding papers covering AFV topics of minor importance. At the end, 34 studies published between 1997 and 2017 were examined for this review. Most of these studies are from journals (94%), the rest from conference proceedings (3%) and other sources (3%) such as key trade magazines. All studies were classified into five categories to answer the aforementioned research questions.

- *Customer demand for alternative fuel vehicles.* The focus of this category is to determine customer demand towards clean passenger cars. Research contributions referring to keywords such as *clean vehicles*, *green car market*, and *car purchase intentions* were examined. Due to the rapidly evolving market, only studies published in the last five years were included.
- *Consumer demand for sustainable materials in car interior.* The goal of this section is to determine customer demand towards environmentally friendly materials for car design. Keywords such as *ecological sustainability*, *green materials*, and *green consumption* were considered. As for the previous category, only studies published in the last five years were included.
- *Key car interior components contributing to consumer perception.* The objective of this category is to identify which components are providing haptic and aesthetic pleasure to customers. Papers referring to keywords such as *multisensory*, *preferred design feature*, and *design variables* were examined for this topic. Selected papers were sorted by number of citations in Google Scholar.
- *Barriers to eco-conscious customer-oriented design.* The focus of this section is to understand what difficulties lie ahead for a systematic translation of consumer demand into design targets. Keywords such as *emotional intent*, *customer needs*, and *affective design* were considered for this topic. As for the previous category, selected papers were sorted by number of citations in Google Scholar.
- *Development of design cues representing environmentally friendly mobility.* The goal of this category is to identify research contributions focusing on defining *green* design cues for vehicles. Research contributions referring to keywords such as *green cue*, *product personality*, and *user-centred-design* were examined for this topic. As for the previous two categories, selected papers were sorted by number of citations in Google Scholar.

## 3 Findings

### 3.1 Customer Demand for Alternative Fuel Vehicles

Seven papers [5-11] were chosen for the purpose of this section. Due to the broad variety of vehicle types included, the term *alternative fuel vehicle* is used inconsistently in literature. In some contributions, AFVs are referred to as NGVs, HEVs, PHEVs, BEVs, BVs, and FCEVs [5, 7]. Other works limit their research on fewer vehicle types, e.g. BEVs and PHEVs [11], when referring to the same term. Due to this inconsistent term usage, analysed car typologies, adopted methods, and chosen geographical markets of study are here specified for each selected paper, Table 1.

A previous work [10] covered a wide geographical area and focused on electric vehicles (i.e. BEVs, FCEVs, HEVs, and PHEVs) to analyse heterogeneous interacting vehicle-consumer factors, including consumer

Table 1: Selected research contributions to identify customer demand for AFVs

Study	AFVs	Methods	Geographical markets
Achtnicht [5]	BEVs, BVs, FCEVs, HEVs, NGVs, PHEVs	Survey, discrete choice analysis	Germany
Egbue and Long [6]	BEVs, HEVs, PHEVs	Survey, chi-square test analysis	U.S.
Hackbarth and Madlener [7]	BEVs, BVs, FCEVs, HEVs, NGVs, PHEVs	Survey, discrete choice analysis	Germany
Hur et al. [8]	HEVs, PHEVs	Survey, partial least squares analysis	U.S.
Jensen et al. [9]	BEVs	Double survey, joint hybrid choice analysis	Denmark
Rossini et al. [10]	BEVs, FCEVs, HEVs, PHEVs	Literature review	China, Europe, Japan, Republic of Korea, U.S.
Tanaka et al. [11]	BEVs, PHEVs	Survey, comparative discrete choice analysis	Japan, U.S.

values regarding financial versus non-financial concerns in vehicle purchase. The four main barriers influencing the market penetration of electric vehicles (EVs) in the examined literature are of a technological and economical kind: batteries charging (21% of the examined publications), specific issues (i.e. fuel cells costs, hydrogen production from fossil source, and lack of secure facilities for hydrogen delivery and storage) related to FCEVs (19%), inviting purchase price (17%), and the driving range (15%).

As far as U.S. customers are concerned, Egbue and Long [6] focused on BEVs, HEVs, and PHEVs to determine if sustainability issues may influence consumer decision to purchase an EV. Their survey and statistical data analysis from a sample population from the U.S. highlight potential obstacles to consumer adoption of EVs, i.e. the uncertainty of the target group associated with the EV battery technology and the sustainability of fuel source. The latter issue proves that some car buyers still question the sustainability and environmental performance of EVs compared to conventional internal combustion vehicles (ICEVs). Hur et al. [8] focused on elderly (i.e. older than age 60 years) customers in the U.S. to examine the correlations between their *green* consumption value, satisfaction, and loyalty of driving hybrid cars; results demonstrate that the significant variables enhancing customer loyalty are social-, price-, and quality- value, respectively. These findings suggest that elderly consumers believe that driving hybrid cars builds a positive self-image of the people who drive them.

Tanaka et al. [11] compared U.S and Japanese customers to estimate their willingness to pay for BEVs and PHEVs based on the same stated preference survey. The willingness to pay values for fuel cost reduction (\$49.8) and alternative fuel station availability (\$49.8) in the U.S. are almost one and a half times higher than those in Japan (\$36.7 and \$33.6, respectively); conversely, the willingness to pay values for the driving range on a full battery (\$21.5 in U.S. and Japan) and emissions reduction (\$29.0 in U.S.; \$26.2 in Japan) are almost the same in both countries.

As far as European customers are concerned, Jensen et al. [9] tested the stability of customer preferences and attitudes before and after experiencing BEVs in Denmark; data was collected in two waves (i.e. before and after the respondents had a three-month real experience with a BEV) and processed with a joint hybrid choice model (i.e. a discrete choice model including latent variables to measure individual attitudes). Their results show that individual preferences do change after the use of a BEV in real life; however, customer environmental concern does not have a serious effect on the choice of vehicle as driving range does. Achtnicht [5] focused on German customers to examine whether CO<sub>2</sub> emissions per km is a relevant attribute in car choices; his results suggest that, despite some evidence on gender, age and education effects on climate concerns, German car buyers are willing to pay substantial amounts of money to fulfil their responsibility for climate change. Hackbarth and Madlener [7] addressed German car buyers as well to analyse the potential demand for privately used AFVs. According to their work, younger (i.e. younger than age 44 years)

customers with high education background and environmental consciousness are more willing to buy AFVs, especially urban drivers of small cars with access to a parking lot equipped with a socket.

### 3.2 Customer Demand for Sustainable Materials in Car Interior

The fact that only one contribution published in the last five years could be identified for the purpose of this section proves the analysis of customer demand for sustainable materials in vehicle interior to be an under-researched field. Hetterich et al. [12] focused on German potential customers to explore the demand for ecological car interiors made of *greener* materials; in order to achieve their objectives, the authors combined a qualitative (i.e. a semi-structured interview) with a quantitative (i.e. a survey using multi-item scales for measuring customer behaviour based on literature review) research methodology. Despite specific prejudices towards renewable materials concerning visual, haptic, and wear properties, the qualitative research displays a general customer agreement that a car interior made of natural or rather renewable resources projects an eco-friendly image to consumers. Nearly three-quarters of the respondents involved in the quantitative research support this statement. Moreover, 66% of the respondents would pay extra charge for sustainable car components in the interior. In particular, 30% of the respondents would pay up to 1% while 27% would pay up to 3.5%. The results provided by [12] suggest that car manufacturers should consider consumer awareness towards the environment: from a strategic perspective, product development should target function, weight, quality and costs as well as ecological sustainability.

### 3.3 Key Car Interior Components Contributing to Consumer Perception

Nine papers [13-21] were selected for the purpose of this section. Four studies [13-15, 19] on consumer perception focus on visual design characteristics of car interior parts only (e.g. shape, colour, size, etc.), including one contribution [19] addressing also visual material characteristics. One article [18] addresses haptic perception of material properties; another contribution [17] focuses on auditory aspects of car components, and two works [16, 20] focus on their auditory, haptic, and visual aspects. Finally, one research contribution [21] specifically addresses haptic and visual perception of materials in vehicle interior.

In order to be consistent when addressing the same car components, terminology has been adapted in some papers. The methods adopted, the perception variables addressed as well as the chosen car interior components are specified for each selected paper, Table 2. According to selected literature, seven components contribute to the definition of a multisensory experience in car interior: car door, centre console, centre tunnel console, crash pad, dashboard, seats, and steering wheel. Other components of minor importance mentioned in literature are the rear view mirror [13, 15], seatbelts and boot door [16], pillars as well as windshield and roof [19].

- *Car doors*. They provide access to the passenger compartment and are characterised by an exterior and an interior side. The former contrasts in its design and finish from the latter, which is typically equipped with a door card/panel to add decorative trims and functional features such as handles. Three contributions out of nine [16, 15, 19] addressed this part. Montignies et al. [16] included door handles in their customer perception analysis, Parizet et al. [17] specifically addressed the driver's door, and Tanoue et al. [19] considered car door interior trims.
- *Centre console*. It refers to the control-bearing surfaces in the centre of the front of vehicle interior. This part is inserted into the crash pad using material inlays and paint finishes, and it often merges with the centre tunnel console to offer storage compartments. Six contributions out of nine [13, 15, 16, 19-21] included the centre console to analyse customer perception. Faerber et al. [13] as well as Leder and Carbon [15] considered middle fresh air nozzles as well. Tanoue et al. [19] considered the centre console and the centre tunnel console as one macro component to define measurement points of vehicle centre. While two contribution address buttons [16, 20], Wellings et al. [20] specifically focused on push-switches for audio and ventilation control. Finally, You et al. [21] addressed the perception of the audio panel as well as specific materials inlays, i.e. wood- and metal-grain.
- *Centre tunnel console*. In rear- and all-wheel drive cars, this component can also be referred to as transmission tunnel. In addition to storage compartments, the hand brake and the gear lever are usually located in the centre tunnel console. The former has lately been increasingly substituted by electric

Table 2: Selected research contributions to define key car interior components contributing to consumer perception

Study	Methods	Perception variables	Components considered
Faerber et al. [13]	Picture stimuli	Form (3D) and shape (2D) features	Centre console, centre tunnel console, crash pad, dashboard, rear-view mirror, seats, steering wheel
Jindo and Hirasago [14]	Kansei engineering methodology	a) Indicator shape, lettering, scale type, starting point b) pad area, pad surface shape, pad upper side shape, spokes' number	a) Dashboard; b) steering wheel
Leder and Carbon [15]	Drawing stimuli	Form (3D) and shape (2D) features	Centre console, centre tunnel console, crash pad, dashboard, rear-view mirror, seats, steering wheel
Montignies et al. [16]	Product evaluation	Auditory, haptic, visual aspects	Belt, boot door, car door, centre console, centre tunnel console, crash pad, dashboard
Parizet et al. [17]	Audio stimuli	Auditory aspects	Car door
Picard et al. [18]	Sample material evaluation	Haptics	Seats
Tanoue et al. [19]	Kansei engineering methodology	Colour, dimension measurement points, material type, number of items, shape, size	Car door, centre console, centre tunnel console, crash pad, dashboard, pillars, roof, seats, steering wheel, windshield
Wellings et al. [20]	Product evaluation	Auditory, haptic, visual aspects of switch-feel quality	Centre console
You et al. [21]	Product evaluation	Material typology and attributes including colour aspects, embossing features, surface texture, shininess	Centre console, centre tunnel console, crash pad, steering wheel

parking brake systems that engage automatically when the engine is stopped and is released when the gas pedal is pressed. The latter is referred to as *gear stick* (i.e. manual transmission) or as *gear selector* (i.e. automatic transmission), and it has a gear knob that acts as the handle for the lever. Five papers out of nine [13, 15, 16, 19, 21] included this car component. In addition to the considerations on dimension presented by Tanoue et al. [19], Montignies et al. [16] addressed the gear lever, and You et al. [21] focused on user's material perception of gear knobs.

- *Crash pad*. It is intended here as the element responsible for holding and surrounding the front of vehicle interior as well as for protecting occupants in the event of an accident or sudden stop. Five contributions out of nine [13, 15, 16, 19, 21] address this part, and often they use different terminologies when referring

to this component. While You et al. [21] expressively name this part in their work, other contributions refer to this component as *dashboard* [13], *storage boxes* [16], or *passenger side instrument panel* [19].

- *Dashboard*. Also known as instrument panel, this component refers to the part of the crash pad located directly ahead of the driver to display instrumentation (i.e. Instrument cluster) and controls for vehicle operation. Five contributions out of nine [13-16, 19] address this interior component. Faerber et al. [13] as well as Leder and Carbon [15] also considered side fresh air nozzles. Jindo and Hirasago [14] focused on design elements of the instrument cluster, i.e. the speedometer. Tanoue et al. [19] also considered disposition of dashboard with respect to door trims contact points to define key measurement points in vehicle interior.
- *Seats*. They are placed as bucket and bench configuration at the front and at the rear of the vehicle, respectively. Front seats are usually made of several adjustable parts, including armrest, backrest with lumbar support, headrest, seat base, and seat track. In order to improve seat comfort and withstand prolonged use at the same time, car seats are usually covered with fabrics. Four contributions out of nine [13, 15, 18, 19] address this interior component. Among them, Picard et al. [18] specifically focussed on car seat fabrics.
- *Steering wheel*. This component is manipulated by the driver to interact with the steering system, either through direct mechanical contact or with the assistance of computer-controlled motors. Five contributions out of nine [13-15, 19, 21] address this interior component. Among them, Jindo and Hirasago [14] as well as You et al. [21] addressed the correlations between customer perceptions of steering wheel and their features.

### 3.4 Barriers to Eco-Conscious Customer-Oriented Design

Ten papers [22-31] were chosen for the purpose of this section. All studies were sorted by number of citations as stated in section 2, except form one recent contribution [29] that has been included for the relevance of the chosen topic. Four studies [22, 26, 29, 31] explore sustainability and AFV design. In particular, two papers [29, 31] focus on material sustainability issues. While two chosen studies [23, 27] address product personality, only one research work [23] uses empirical evidence. Two papers [24, 25] focus on the differences between designer and customer perception. In particular, one study [24] specifically addresses car design. Finally, two research contributions deal with the product design process [28, 30], i.e. present material selection methods for industrial designers [28] as well as differences between the processes followed by design engineers and industrial designers [30].

In order to avoid misunderstanding between *product-* and *industrial design*, a brief terminology clarification is provided. *Product design* is intended here as an ensemble of disciplines involved in designing a specific product (e.g. design, engineering, marketing and so on), while *industrial design* is defined here as the monodisciplinary task of the designer involved in the whole product design process. The topic of each paper, the methods adopted, and the barrier addressed are specified for each selected work, Table 3. According to selected literature, four macro barriers can prevent the successful targeting of environment-conscious car buyers: an AFV-related-, a product-related-, a discipline-related-, and a process-related- issue.

- *AFV-related*. As section 3.1 already highlighted some scepticism of car buyers regarding the sustainability and overall environmental performance of EVs compared to ICEVs, material selection for the design of AFVs is a key issue. While fibre-reinforced plastics such as carbon fibre-reinforced polymers are implemented to improve car lightweight [26] and, consequently, the sustainability of the use phase of cars, novel indicators assessing the criticality of these materials are still needed to analyse socio-economic perspectives. In particular, high energy consumption for lightweight materials production [31] as well as recyclability of carbon fibres [29]. Failing to address sustainable car production and recycling of aggregates would question the whole purpose of purchasing an AFV, ultimately shifting the concept of driving an AFV from sustainable consumption to *green* consumerism [22].
- *Discipline-related*. It appears that industrial designers and customers perceive product form differently, due to two main reasons: designers and users have different impressions linked to the same product; the same evaluative term or image-word has a different meaning for the two groups [25]. This different

Table 3: Selected research contributions to identify barriers to eco-conscious customer-oriented design

Study	Topic	Methods	Barrier addressed
Akenji [22]	Sustainable consumption	Essay	AFV-related
Govers and Schoormans [23]	Product personality	Picture stimuli, survey	Product-related
Helander et al. [24]	Designer vs. customer	Citarasa Engineering methodology	Discipline-related
Hsu et al. [25]	Designer vs. customer	Picture stimuli, semantic differential methodology	Discipline-related
Jacob [26]	EV design	News article / report	AFV-related
Janlert and Stolterman [27]	Product personality	Essay	Product-related
Karana et al. [28]	Materials selection process in product design	Literature review, survey	Process-related
Pillain et al. [29]	Carbon fibre recycling	Literature review	AFV-related
Tovey [30]	Industrial design	Essay	Process-related
Witik et al. [31]	Sustainability of lightweight materials	Life cycle assessment, life cycle cost analysis	AFV-related

relationship between image-word and design elements for designers and customers could cause a discrepancy between the conceptual model of *green* design cues of both groups. Specifically in car design, valid measures to assess affective responses of customers to design are still needed to generate successful affective design [24]. Therefore, car designers still have to understand how emotional design features associated with sustainability can be included while designing.

- *Product personality-related.* Products are symbols by which customers convey something about themselves to themselves and to others, and the word *personality* in product personality refers to the fact that people use human personality characteristics to describe their impression of a product [23]. However, the overall description of personality of a single product is mainly defined by its appearance [27]. Since the act of being environmentally friendly for humans is only related to behaviour (e.g. protecting water sources, helping clean the air, or protecting land and wildlife), no visual symbolic meanings may be suitable for the definition of a *green* product personality.
- *Process-related.* Within the product design process, a close relationship between industrial design and design engineering exists because both disciplines are concerned with manufactured products. However, while systematic methods are followed in the field of design engineering to face the product design process, practicing industrial designers are less rigorous in applying scientific calculations while defining product personality, and are more familiar with intuitive processes and graphic languages [30]. Therefore, the existing material selection sources and methodologies available for product design address design engineers and do not include sensorial aspects of materials characteristics for the conceptual design phase [28]. As the role of sensorial aspects and intangible characteristics of materials is crucial for incorporating eco-friendly meanings to their products through appropriate choices of material, industrial designer are currently not provided with a tool to express their intentions in the design process.

### 3.5 Development of Design Cues Representing Environmentally Friendly Mobility

Seven papers [32-38] were selected for the purpose of this section. The extremely low number of citations (i.e. between 0 and 2, excluding self-citations) of four contributions out of six [32, 35, 36, 38] proves the explored topic to be an under-researched field. Three studies [32, 34, 38] provide insight into automotive applications of environmentally friendly materials. In particular, one study [38] specifically addresses BEV interior. While two studies [35, 36] attempt the development of design cues for AFVs, only one contribution [35] addresses car interior. One work [33] describes a procedure to define product experience through

materials in the design process, while another contribution [37] presents recommendations for helping designers of eco-products to follow a pro-environmental behaviour.

The topic of each work, the methods adopted, and the relevance for the purpose of this section are specified for each selected paper, Table 4. Following the four macro barriers expressed in the previous section, useful information for the development of design cues representing eco-friendly mobility is grouped as follows.

- *Guidance for designing green AFVs.* Considering the discipline-related barrier based in the inability of designers to define emotional design features universally perceived by customers as *sustainable*, the work of MacDonald and She [37] provides insight into the cognitive approach to designing *green* products. Among the seven cognitive concepts presented by the authors, customer *decision heuristics*, i.e. the ensemble of shortcuts that exist in user's mind in order to simplify judgments and decisions, and consumer *trust* towards the pro-environmental claims made by the product are of specific interest for the scope of this paper. To address these two issues, the authors advise designers to identify and use perceptual product cues that communicate environmental impact, e.g. by following nature-inspired shapes and forms that evoke environmental concern. This can help building trust in the customer, as the relationship between the *crux* (i.e. difficult for people to assess) product attribute *eco-friendly* and the *sentinel* (i.e. easy to assess and with a perceived association with the *crux* attribute) product attribute *nature* would ultimately generate a trustworthy and credible link between product and sustainability [37].
- *Including sensorial aspects of materials in AFV design.* To overcome the process-related barrier mentioned in the previous section, Karana et al. [33] present the Material Driven Design (MDD) methodology, which considers technical properties of materials as well as their experiential qualities in relation to how they are perceived by users. In particular, the presented methodology aims at facilitating the design for material experiences when a given material is the point of departure in the design process. Four steps define MDD: *understanding the material* through technical and experiential characterization, *creating materials experience vision*, *manifesting materials experience patterns*, and *designing material/product concepts*. According to the authors, the nature of the given design project might result in omission of one or more steps, or alter the depth to which they are conducted. While the authors present some evidence for the effectiveness of MDD, a thorough assessment of the methodology with end users in real life contexts is still missing.

Table 4: Selected research contributions to develop design cues representing environmentally friendly mobility

Study	Topic	Methods	Relevance
Dunne et al. [32]	Natural fibres for automotive applications	Literature review	Potential of green materials for AFV design
Karana et al. [33]	Material Driven Design	New methodology development	Including sensorial aspects of materials in AFV design
Koronis et al. [34]	Green composites for automotive applications	Literature review	Potential of green materials for AFV design
Landau et al [35]	Development of EV design cues for car interior	Sample material evaluation	Preferences of users towards design cues for AFVs
Lee et al. [36]	Development of green design cues for HEV exterior	Drawing stimuli	Preferences of users towards design cues for AFVs
MacDonald and She [37]	Cognitive concepts for eco-product design	Literature review	Guidance for designing green AFVs
Schmiedel et al. [38]	Use of visible natural fibres in car interior	News article / report	Potential of green materials for AFV design

- *Potential of green materials for AFV design.* Eco-friendly composites may be the solution to partly overcome the previously highlighted AFV-related barrier. Vehicles could be *greener* due to the replacement of synthetic fibres with natural ones and, at the same time, lighter as well since natural fibres can be less dense than the synthetic types (e.g. carbon or glass). Currently, coir, flax, hemp, jute, kenaf, sisal, and wood are implemented in cars as reinforcement for elastomers, thermoplastics, and thermosets [32]. Other natural fibres suitable for automotive applications are abaca, curaua, and ramie [34]. While their usage is still challenging for structural parts of car exterior panels, natural fibres are used for a variety of interior components [34]. They include dashboard, door panels and trims, headliner panel, pillar cover panels, seats (i.e. back panels, padding, and upholstery), and sun visors [32]. BMW focused on door panelling and on an instrument panel cover to implement visual natural fibres in the interior of the BEV i3 model, featuring a kenaf natural fibre non-woven fabric that is combined with fibres made of polypropylene. The kenaf door panelling is able to reduce the door substrate by 1300g/m<sup>2</sup> compared to conventional plastics door substrates with film coating; at the same time, a thin black PP decorative film is laminated onto the surface in the manufacturing process to provide a pleasant surface feel to the customer [38]. Currently, this car is the only purpose designed AFV featuring composite natural fibre materials to both fulfil lightweight demands and bring out the sustainable character of the vehicle by making the material visible to the passengers.
- *Preferences of users towards design cues for AFVs.* Information regarding users' preferences for colour, texture, shape, and materials for AFVs is valuable to partly defeat the aforementioned product personality-related obstacle. Landau et al. [35] focused on EVs to identify correlation between materials and product personality features to define design cues representing electromobility in car interior; by having users create mood boards using 18 pre-selected materials, tactile experiences of various materials were explored to inform interior design of EVs. The authors defined six characteristics according to literature review to describe electromobility: *clean, driving pleasure, energy-efficient, innovative, low-noise, and sustainable*. The results provided by [35] show that, despite the great variation in the degree of agreement about associated materials, users seem to have a clear view about what materials represent sustainability: this word was associated with a *green* artificial turf by 46% of the involved participants. One of the two experiments presented by Lee et al. [36] aimed at identifying design cues that signal environmental friendliness for car exterior of HEVs; their results provide information on user preferences of shape, texture, and colour for AFV design. Rounded, simple, and matte shapes can contribute to signalise *green* design to customers, while colours like white, green, and blue are perceived as eco-friendly [36]. In this regard, it should be noted that some German car manufacturer currently use blue as colour to represent environmental friendly technology (e.g. *BlueTEC* for Mercedes-Benz, *BlueMotion* for Volkswagen) as well as mobility (e.g. exterior and interior colours for the BMW *I* models).

## 4 Implications

The social value associated with owning an AFV is clearly perceived by customers. However, although sustainability and emissions-reduction benefits of AFVs have a major influence on them, the specific acceptance of EVs mainly depends on battery technology that is responsible for car driving range and charging time. Policy makers should therefore address these socio-technical hurdles to improve the market penetration of these specific types of AFV. Moreover, future work should identify consumer demand for sustainable materials in car interior, as this remains an unexplored field of investigation.

The car doors, centre console, centre tunnel console, crash pad, dashboard, seats, and steering wheel are key car interior components contributing to consumer perception, and they have to be addressed to further unify the field of environmentally conscious design with the domain of product personality in the design of AFVs. To pursue this objective effectively, an AFV-related-, a product-related-, a discipline-related-, and a process-related- macro barrier to eco-conscious customer-oriented design have to be conquered first.

Some guidance reported in this paper should support designers in overcoming the discipline-related obstacle to ultimately successfully designing *green* AFVs, while previous work carried out to identify design cues for AFVs should help tackle the underlined product personality-related barrier. Despite the potential of environmentally friendly composites for the design of AFV interiors, carmakers should face the high energy consumption needed for the production of lightweight materials as well as the recyclability of carbon and glass fibre-reinforced polymers to successfully overcoming the described AFV-related obstacle. Finally,

future cross-disciplinary research on material design should develop a multisensory mood-board to enable practising designers to make informed decisions on the materials to be used in order to evoke the intended experience, thus defeating the identified process-related barrier.

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