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► **To cite this version:**

Egon Ostrosi, Jean-Bernard Bluntzer, Zaifang Zhang, Josip Stjepandić. Car style-holon recognition in computer-aided design. *Journal of Computational Design and Engineering*, 2019, 6 (4), pp.719-738. 10.1016/j.jcde.2018.10.005 . hal-03162615

HAL Id: hal-03162615

<https://hal.science/hal-03162615>

Submitted on 20 Jul 2022

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Car style-holon recognition in computer-aided design

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ABSTRACT

Multi-scale design can presumably stimulate greater intelligence in computer-aided design (CAD). Using the style-holon concept, this paper proposes a computational approach to address multi-scale style recognition for automobiles. A style-holon is both *a whole*—it contains sub-styles of which it is composed—as well as a *part* of a broader style. In this paper, we first apply a variable precision rough set-based approach to car evaluation and ranking. Secondly, we extracted and subsequently computed the each car's characteristic lines from the CAD models. Finally, we identified style-holons using the property of a double-headed style-holon. A style-holon is necessarily included in a typical vertical arrangement with progressive accumulation and forms a nested hierarchical order called a *holarchy of styles*. We adopted an interactive cluster analysis to recognize style-holons. Our results demonstrate that car style depended on each brand's individual strategy: *a car is a form endowed with some structural stability*. The style-holon also demonstrated that the evolution of characteristic lines should preserve the property of *functional homeostasis* (the same functional states) as well as the property of *homeorhesis* (the same stable course of change). For many car companies, stable brand recognition is an important design specification. The proposed approach was used to analyse a set of car styles as well as to assist in the design of characteristic model lines. A designer can also use this approach to evaluate whether or not the strategic requirement—style alignment with the style-holon of benchmarked cars—is satisfied.

KEYWORDS

Car style; CAD of style, style analysis, brand style, rough set-based evaluation, style-holon.

1. INTRODUCTION

CAD modelling of vehicle morphology is an essential part of engineering design activity in the automotive industry (Vignesh et al., 2007). This type of modelling integrates quantitative and qualitative criteria in order to abstract, simplify, and formalize data. It is also a process that generates multiple views of the final engineering design and can therefore incorporate a range of design perspectives, from customer requirements to production system prerequisites (Stjepandić et al., 2015b). Indeed, an engineering view of the morphology contains a model that represents only those aspects of the car that are relevant for the corresponding phase. In many situations, a change to one view of the morphology model may conflict with other engineering views, such as the types of conflicts that often arise between industrial design and engineering design (Gudem et al., 2011). In these types of situations, the morphology model of some engineering views needs to be adapted in order to provide consistency across all morphology models.

The history of the automotive industry demonstrates that car morphology evolves over time while simultaneously preserving the strength of brand identity. Overall, vehicle modelling is subject to a strong pressure of competition. Thus, designers endeavour to both innovate a morphology while also adapting it to a novel context. Morphological features play an inevitable role in the representation and perception of a car. These morphological features are recurrent, identifiable geometrical and topological elements that integrate the subjective design world with the objective design world.

A morphological feature is also a means of expression, communication, and integration. The relationship between morphological features like language and utility (Ostrosi and Ferney, 2007), as well as the relationship between language, utility, and the ease of use by designers are just a few of the problems that plague the CAD vehicle modelling process. The semantic frameworks, formal aesthetic, and gestalt theories established at the cognitive level indirectly incorporate formal aesthetic principles, such as geometry, dimension, texture, material, colour, graphics, and detailing (Ali and Liem, 2014). Understanding which car morphologies are successful in the market allows designers to understand the tendency of creation, evolution, and destruction of morphological features.

This paper focuses on car style because it is an important expression of car morphology. Car style is dominant among the geometrical and physical properties of the car because it often comes out of the fundamental property of the car. Customers first encounter a car through its geometrical and physical appearance or style, and this appearance impacts the

customer's emotional response. Emotion plays an important role in motivating people to interact while providing internal guidelines for rationalizing their actions (Fukuda, 2011). Emotion can also play an important role in providing general customer satisfaction for a car or car-related products, also known as a product society (Fukuda, 2016). Today, as performance rapidly transitions from functional performance to emotional performance, it is important to take this into account throughout car morphology and modelling.

From a structural point of view, a good style accomplishes both social and functional goals (Shelley, 2017). Knowledge-based engineering frameworks (Stadler and Hirz, 2016) or ontologies (Cheutet et al., 2008) are used to integrate car styling with engineering functionalities while also supporting the conceptual design phase for the car. This should also preserve the automobile's brand identity (Sareh and Rowson, 2009) through a signature style (Chan, 2000). The relationship between the mathematical definition of the style and its qualitative definition, based on data coming from user interviews, has revealed a significant relationship between geometry and emotion (Lucchi et al., 2015). Some recent research has also attempted to locate methods for quantifying style differences and identifying unique design elements (Hyun et al., 2015). The style is also considered as an incremental, and not as a radical, innovation factor (Calabrese, 2011). Famous stylist Giugiaro reported that a stylist tries to compress the form and make it streamlined. The streamlined form therefore represents a well-balanced, elegant, and refined unicum without forced superficial gloss (Giugiaro, 2007).

Perception, according to Thom¹ (1988a), is a discontinuous phenomenon in a continuous background. This discontinuity, which presupposes the continuous, is the first experience in all reception of phenomena. Uniformity and rupture of uniformity are the external elements that stimulate perception. Latency designates this continuous background, all that appears, all that is possible, and all that can be perceived. On this continuum, there is a discontinuity determined either by the salience of the car or by the pregnancy of the car. Salience is what distinguishes the car from others or from the environment. This salience is built on the identity of a strong brand. Salience is then the geometrical and physical form of the car, which distinguishes the brand from its competition. The form's pregnancy is closely related to the intentions and the concerns of the human. It is then any form of the car that every human, from user to the stylist, can see from his or her point of view. The pregnancy is thus a cognitive salience. A stylist designs both the salience and the pregnancy of the brand. Given a

¹ René Thom (2 September 1923 – 25 October 2002) French mathematician (topologist) and philosophe. Thom (Fields Medal in 1958) is the founder of catastrophe theory.

set of different cars, a certain brand will be salient if it can be distinguished on the basis of its geometrical and physical properties. Thus, the geometrical and physical salience of the cars, designed by the stylist, plays an important role in the success of the brand.

Knowing that recognition is regarded as a basic attribute of human experts, features emerging from feature recognition can be considered as one of the first “intelligent objects” introduced in a CAD modelling (Fougères and Ostrosi, 2018). This paper contributes brand recognition of the style as an important step toward CAD modelling of the morphology by the stylist. The hypothesis of the paper contains two parts. First, the car style represents a specific geometry that can implicitly integrate cultural dimensions. Cultural dimension implies that styles can be necessarily included in a typical vertical arrangement, with progressive accumulation, and form a nested hierarchical order for a culture (Hall, 1989; Hofstede, 2002; Minkov and Hofstede, 2011; Trompenaars, 1996). Second, the distance between the car’s morphology allows for recognition of the self-embedding of car styles in a given context. The holon is a very interesting structural concept for the description of the property of self-embedding of car styles and for overcoming the continuous-discontinuous distinction of car style.

The holon is something that is simultaneously a whole and a part of a greater whole, which contains elements, or sub-parts, of which it is composed, and which also provides its structural and functional meaning. Holons are complete by themselves, and hence can be treated as a unit. However, they are also part of a larger system. Many applications have been proposed using the concept of the holon, such as holonic systems design (Valckenaers and Van Brussel, 2005), holonic manufacturing (Valckenaers et al., 1998; Van Brussel et al., 1999, 1998), manufacturing control and scheduling (Leitão and Restivo, 2008, 2006), holonic assembly (Arai et al., 2001; Hsieh, 2008) are some engineering applications. The concept of holon is also applied in product and system design (Hashemian, 2005), design for configurations (Issa et al., 2017) as well as complex adaptive systems modelling (Honma et al., 1998). All of these applications are characterized by the double-headed property of the holons, meaning that holons must be included in a typical vertical arrangement, called a *holarchy*.

The *holarchy* can represent progressive accumulation and nested hierarchical order of styles. The architecture of holons can show both the “horizontal” and “vertical” self-similarity of car styles. Horizontal self-similarity relates to self-similarity across different car styles on one level of aggregation while vertical self-similarity refers to self-similarity across multiple levels of aggregation. *Thus, in order to analyse and capture the self-embedding and*

self-similarity property of car style, this research introduces the concept of the style-holon.

The organization of the paper is as follows: The second section presents the state of art for car modelling. In the third section, a CAD approach for style recognition is presented. The fourth section demonstrates the application of the method. In the final section, conclusions and future developments are proposed.

2. STATE OF THE ART

A style is a specific aspect of a stylist's expression in a product, which integrates brand identity and strategy. A style acts as an interpreter between the product and the customer. This interpretation or communication is realised through designing the salience and the pregnancy of product. Computational methods are used to generate good products and develop an understanding of what constitutes good art objects. These methods can assist in the style design by providing explication and easy justification for interpretation. In this section, we provide an overview of these issues followed by a discussion.

2.1. Style and brand identity

Brand identity must be the foundation of any design strategy for a product. These design strategies drive the aspects and constraints of all future products. Indeed, the design and development of a product proceeds from of a collaborative and distributed process. Distributed designers work and interact actively with the design and development of the product according to the aspects and constraints of their domains. The evaluation of the distance between target design parameters and real design parameters continuously characterize the design activity (Choulier et al., 2015). In this context, an important design constraint of a brand is to create a strong product identity that differentiates it from other, similar products. For a strong brand, designers need to constantly innovate new ideas that also align with the brand's history (Fanning, 1999). A brand identity is fostered through an association with the physical quality of the product and the experience and appreciation of the brand by the final consumer (Cagan and Vogel, 2002). Brand associations form through personal beliefs, values, and emotions (Abbott et al., 2006). The brand identity should be focused on a design process tailored to a specific styling that can be clearly recognized by customers. The specific form of the product of brand (its style) is often defined throughout the early stages of the design process (Cagan and Vogel, 2002) and establishes the interaction between designers as well as the interaction between the brand and its consumers (McCormack et al., 2004).

The modelling of a car brand should also represent the complex link between both the car

components and the broader brand identity. Integrated with this modelling, the styling has to represent and reinforce the brand identity. Well-known brands in different countries rely, amongst other things, on their expertise and their know-how gained through their history. A car should evolve prudently, satisfying a conservative evolutionary style according to the history of the car model (Randle, 1986) in order to minimise the impact on the customer and their cognitive process. In fact, each brand should know the elements of its very core identity (Kapferer, 2002).

The heritage (Karjalainen, 2007) and cultural identity of a specific region (Bluntzer et al., 2015) are implicitly represented by the stylist in a vehicle's design. The French heritage for Peugeot, Citroën and Renault, the German heritage with Volkswagen (Bluntzer et al., 2015), the Scandinavian heritage for the Volvo brand, the British heritage for the Jaguar brand, the American automotive design heritage for the Cadillac brand, and the Italian heritage for the Alfa Romeo brand (Karjalainen, 2007), are some examples of country and cultural heritage. However, an important issue is how to maintain the stability of a brand's identity following globalisation and the unavoidable dynamic of different cultural perspectives.

2.2. Designing the salience and the pregnancy

A successful brand develops a strong relationship between the design and the customer (De Chernatony, 2001). When the customer is in a contact with a product, he or she attaches, consciously and subconsciously, specific functional and symbolic qualities to the product and develops expectations of how it is supposed to look, feel, and function (Karjalainen, 2007). The style's pregnancy is closely related to the intentions and concerns of the stylist as well as to the customer. The pregnancy is designed through the style of a product to express some ideas to the customer. Product styling is thus carried out to create visual attractiveness in a product (Fenko et al., 2010). The Audi brand states that more than 60% of its customers base their decision to buy a car on the overall style of the product (Kreuzbauer and Malter, 2005). A brand should also have a clear and precise physical salience. In this context, the notion of brand styling is the subject of work in many fields, such as art, marketing, innovation, and product design (Hagtvedt and Patrick, 2008; Mackie, 2011; Person et al., 2008). Visual elements or brand signifiers (Warell and Young, 2011) are important aspects of salient designs. Physical salience is designed by using reoccurring features of the product's brand. That means that the end user can recognize the product's brand by these features, which are carried over or slightly modified from the previous iteration. The visual references, which are embedded in the design features with the intention to be immediately perceived and

recognized, are defined as explicit references (Karjalainen and Warell, 2005). The perception of the feeling provided by the product is considered an implicit reference (Karjalainen, 2007). Visual perception varies across cultures (Segall et al., 1966). “Circular cultures” use curves and are not impacted as much by the types of lines found in “straight and parallel lines’ cultures” design. More generally, an individual's membership in a community, whatever it may be, entails the possibility of specific factors of cognitive salience (Landragin, 2004).

A study with European engineer students from ergonomic, design, and mechanical engineering departments, demonstrated that cars from their home continent were easily recognized, whereas Japanese cars were difficult to recognize, and some cars coming from the USA, such as the Ford F-Series, were somewhat recognizable (Bluntzer et al., 2014a). A similar experiment considering the role of design freedom and brand recognition for automotive designs from four brands found that while brand recognition is highly dependent on the manufacturer, some brands develop a strong negative relationship between design freedom and brand recognition, suggesting that these manufacturers face a significant challenge when evolving their brand styling (Burnap et al., 2016). In addition, an investigation on the influence of aesthetic features on brand recognition of vehicles using a specific car decomposition (Ranscombe et al., 2012) illustrated the importance of the design saliency and pregnancy for a product.

Design saliency and pregnancy through exterior styling and other aesthetic elements are critical to the buying decision as well as to customer satisfaction. Applying formal methods for quantifying the consumer's form preference in a utility function can help product designers to conduct early market research in a continuous design space for finding high utility product shapes (Orsborn et al., 2009). However, an important issue is how to represent the design space with the least number of attributes while still capturing the fundamental form changes that consumers find important.

2.3. Computational styling methods

Computational techniques for product aesthetics design has been developed so that customer perception can be incorporated into product design in a more systematic and intelligent manner (Tang et al., 2013). Computer-assisted procedures have been developed for car style design based on extracting curves from initial sketches (Lin and Yan, 2004). The definition of a perceptual space, built by a multidimensional scaling, and which lead to the definition of interpretable perceptual dimensions, is used in a computational method that integrates customer preferences for a car's headlight, modelled by Bezier curves (Petiot and

Dagher, 2011). The Fourier coefficients of a closed curve are applied in this method to represent the information on the curvature variations.

The most widely used computational modelling methods are shape grammars, first introduced by Stiny and Gips (Stiny and Gips, 1971). A shape grammar is a set of rules, based on the shape that is used to generate design through a series of rule applications beginning with an initial shape (Stiny, 1980, 1977). Shape grammars have been used for understanding and describing different architecture styles. For example, Chinese lattice (Stiny, 1977), Japanese tea houses (Knight, 1981), Wren's churches (Buelinckx, 1993), Wright's prairie houses (Koning and Eizenberg, 1981), Queen Anne houses (Flemming, 1987), and geodesic domes (Shea and Cagan, 1997) are some applications of shape grammars. Shape grammars are powerful decomposition and generative formalism because they possess the topology and geometry-handling capability (Ostrosi et al., 2012b). Shape grammars allow analysis through decomposition and synthesis through production rules. Shape grammars are also used for producing car styles (Bluntzer et al., 2015; McCormack et al., 2004; Orsborn et al., 2006).

Evolutionary Computation is another applied technique for the exploration of car style. Genetic algorithms are used to synthesize car styling based on appearance for design exploration in the concept generation (Hyun and Lee, 2018). Interactive Genetic Algorithm combined with the Fourier decomposition of a 2D profile is proposed to progressively sketch the desired side-view of a car profile (Cluzel et al., 2012). Interactive Genetic Algorithm is a special class of Genetic Algorithms where a human is embedded within the task of selecting individuals. A combination of Fourier decomposition and shape grammar is used for the evaluation similarities and combinations of car style elements (Hyun et al., 2015). Genetic algorithms embody powerful general principles for processing information. However, they do not process knowledge and do not always provide knowledge that can be exploited by a designer. For a designer, the genetic algorithms often remain a black box that provides an answer however they do not provide explication and easy justification for interpretation.

2.4. Discussion

A style is a specific aspect of a stylist's expression in a product. It acts as a carrier of various symbolic meanings. A style is a way to treat the morphologies and put them into a meaningful structure, which we can call the *telling structure*. The *telling structure* is a sequential representation of functional or non-functional morphologies. We can define the telling structure as a structure in which the *tellability* passes from a possible secondary role to the status of a regulatory principle, which becomes a priority while communicating with a

customer. The *tellability*, in a given context and in a given culture depends on some attributes of designed behaviour (for instance, aggressiveness, sportiness, etc.) and their representation by the topology and geometry. It is the break of a regularity, which often forms the structural sequence and establishes the narrative ability of the product. Therefore, the car's design results from designing both the salience (physical salience) and the pregnancy (cognitive salience). However, car designers should also satisfy multiple engineering constraints on the specific form of the product, as well as the transmission of the brand identity to the customer. Though some research shows that it is the designers' job to generate design alternatives while fulfilling brand styles and manufacturing requirements (Thomke, 2001), the trend demonstrates that car design platforms are collaborative and distributed. Interaction is thus a central key to the success of the design (Movahed-Khah et al., 2010). In most cases, the obtained design needs to be consensual in order to be accepted (Ostrosi et al., 2012a). The recognition of style morphology is an important step toward seeking the consensus in CAD modelling of the morphology. The successful car morphologies on the market allow designers to understand the tendency of creation, evolution, and destruction of the morphologies. Being aware of the geometrical and topological similarities of the style, designers can also demonstrate or highlight their innovation by designing both the salience and the pregnancy and defend their intellectual property (Stjepandić et al., 2015a). However, a unique style in an absolute sense does not exist. A style is designed in a cultural context and sometimes becomes a form of design identity (Bluntzer et al., 2015). However, there is an embedding relationship between styles. A style, as with a holon, should exist simultaneously as a self-contained whole in relation to its features, *called characteristic lines*, and as a dependent part when considered from the perspective of the influences from one or more higher level style-holons. This paper analyses and tackles this issue.

3. RESEARCH METHODOLOGY

A computational method is proposed to recognize different car styles, called the *style-holon*. A *style-holon* is defined as a whole that is a part of a greater style whole, which at the same time contains sub-styles, of which it is also composed. Figure 1 shows the architecture of the proposed computational method. The three main phases are as follows:

Phase 1: Evaluation of cars. In this phase, car designers evaluate a set of benchmarked car styles.

Phase 2: Building car – characteristic line model. In this phase, the relationship between the set of benchmarked cars and the set of characteristic lines, represented by their geometry

and topology, is built.

Phase 3: Style-holons recognition. In this phase, the style-holons are recognised. A style-holon is simultaneously a part of a style-holon, and it can be viewed as having styles of its own.

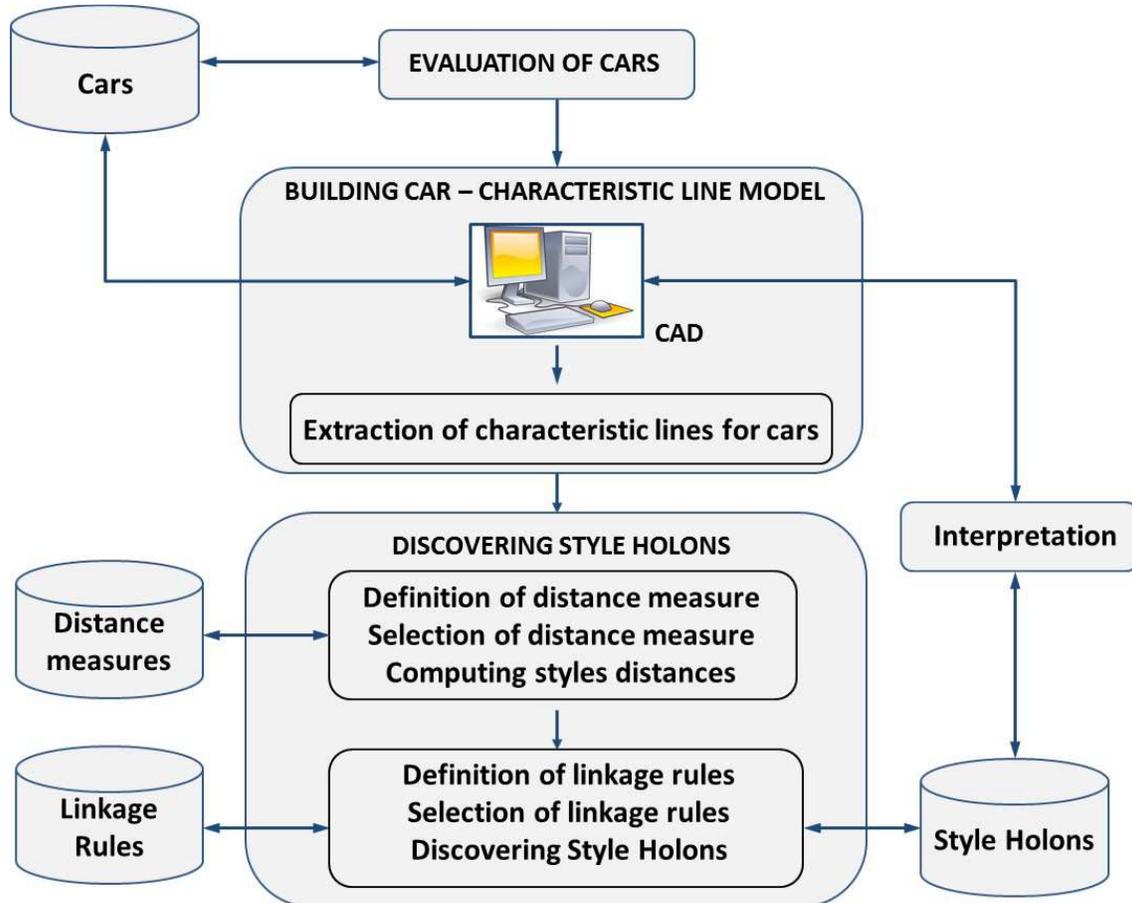


Figure 1 Architecture of the proposed computational method.

3.1. Evaluation of cars

Anytime a new proposed style is conceptualized, it should be benchmarked against existing concurrent styles. The stylist should analyse and compare how this new style is a conservative evolutionary style and how it is competitive with other brands. Since a style-holon both contains and is contained in other style-holons, it bi-directionally influences and is influenced by these style-holons.

Today, designers pay more attention to the value of creative experience (Fukuda, 2017). Thus, knowing that a style integrates aesthetic, emotional, social, and functional goals, the car designers should judge and evaluate the benchmarked car styles. The evaluation of benchmarked car styles should flexibly handle the subjectivity and vagueness during the decision-making process. The variable precision rough set-based approach handles the

subjectivity and vagueness during the decision-making process. The variable precision rough set-based approach (Zhang et al., 2017) is applied here for car evaluation.

The first element of evaluation is the group of designers $G = \{a_1, a_2, \dots, a_h\}$, the second element is the set of cars $V = \{v_1, v_2, \dots, v_n\}$, and the third element is the set of evaluation criteria $S = \{s_1, s_2, \dots, s_k\}$. Designers may have different cognitive vagueness for car evaluation for a given criterion. To express the degree of cognitive vagueness specific to a designer's judgment, a factor of variable precision β is defined in $[0,1]$. If the individual certainty is increasing, then the range of vagueness is decreasing, with the decrease of β , and vice versa. Three scenarios for the definition of the factor of variable precision β can be distinguished:

1. “ $\beta = 0$ ” means “no vagueness.” In this scenario, the designers' judgment is completely determined and its uncertainty is equal to zero in respect to designer cognition.
2. “ $0 < \beta < 1$ ” means “partial vagueness.” In this scenario, the designers' judgment is partially uncertain.
3. “ $\beta = 1$ ” means “complete vagueness.” In this scenario, the designers' judgment is completely uncertain.

Let us give a criterion $s \in S$. Every designer $a \in G$ judges a car $v \in V$ according to the criteria $s \in S$. In order to formally compare cars $v \in V$ according to the criterion $s \in S$, it is necessary to formally measure the designer judgments. For this purpose, a numeric function $p \in]0,10]$ is used in terms of the designer judgment. A judgment set $P_{v,s}$ with h ordered judgments, following the relationship order: $p_1 \leq p_2 \leq \dots \leq p_h$ can be formed (1):

$$P_{v,s} = \{p_1, p_2, \dots, p_h\} \quad (1)$$

Let $p_i \in]0,10]$ be a judgment in the set $P_{v,s}$ and d the distance of $P_{v,s}$, defined as $d = p_h - p_1$. The designer' judgment p_i under uncertainty can be expressed by the rough numbers. Rough numbers can provide flexibility and accuracy of designer's judgment. The rough number can be calculated by using a variable precision rough set method. The lower approximation $\underline{Apr}^\beta(p_i)$ and the upper approximation $\overline{Apr}^\beta(p_i)$ of the judgment p_i can be identified as follows:

$$\underline{Apr}^\beta(p_i) = \cup \{p_j \in P_{v,s} \mid p_j \leq p_i, (p_i - p_j) \leq \beta d\} \quad (2a)$$

$$\overline{Apr}^\beta(p_i) = \cup \{p_j \in P_{v,s} \mid p_j \geq p_i, (p_j - p_i) \leq \beta d\} \quad (2b)$$

The judgment sets (2a) and (2b) can be converted into a rough number form through the

calculation of lower approximation and upper approximation. The judgment p_i is then represented by a rough number $R(p_i)$ defined by its lower limit p_i^L and upper limit p_i^U as follows:

$$R(p_i) = [p_i^L, p_i^U] \quad (3)$$

$$\text{where: } p_i^L = \sqrt[q]{(\prod x_{ij})}, p_i^U = \sqrt[r]{(\prod y_{ij})}$$

where x_{ij} and y_{ij} are the elements of the lower approximation set $\underline{Apr}^\beta(p_i)$ and the upper approximation set $\overline{Apr}^\beta(p_i)$ of p_i respectively, and q and r are the number of elements in the two sets respectively.

Thus, for every factor of variable precision β , the judgment set (1) is expressed by a rough judgment set as follows:

$$R(P_{v,s}) = \{[p_1^L, p_1^U], [p_2^L, p_2^U], \dots, [p_h^L, p_h^U]\} \quad (4)$$

The judgments of designers $a \in G$ for a car $v \in V$ according to the criterion $s \in S$, (Equation 4) can be evaluated using the concept of consensus. Consensus, first mentioned in social and sociological sciences (Susskind and Cruikshank, 1987), can be used to compute the degree of agreement among all the designers' evaluation (Ostrosi et al., 2012a). Group certainty reflects the consensus in a judgment set $P_{v,s}$. Group certainty is higher with the lower distance d and closer to the individual judgments. Therefore, the deviation degree between each individual judgment, represented by the rough number $R(p_i) = [p_i^L, p_i^U]$ and the group judgment, represented by the rough number $R(B_{v,s}) = [b_{v,s}^L, b_{v,s}^U]$, should be as small as possible. To represent the group judgment, a rough least square model (RLSM) can be used to calculate the rough number $R(B_{v,s}) = [b_{v,s}^L, b_{v,s}^U]$ as follows:

$$\text{Min Di} = \sum_{i=1}^h \left((b_{v,s}^L - p_i^L)^2 + (b_{v,s}^U - p_i^U)^2 \right) \quad (6)$$

$$\text{s.t. } p_1^L \leq b_{v,s}^L \leq p_h^L$$

$$p_1^U \leq b_{v,s}^U \leq p_h^U$$

where Di is the deviation degree between each individual judgment and the final group judgment, $b_{v,s}^L$ and $b_{v,s}^U$ are respectively the lower limit and upper limit of $R(B_{v,s})$.

Thus, the rough number $R(B_{v,s}) = [b_{v,s}^L, b_{v,s}^U]$ measures the degree of consensus of the group designers $G = \{a_1, a_2, \dots, a_h\}$ on the evaluation of the car $v \in V$ with the criterion $s \in S$. The group judgments on the car $v \in V$ according to the set of criteria $S = \{s_1, s_2, \dots, s_k\}$ can be expressed in the form of consensus rough set:

$$R(B_{v,s}) = \{[b_{v,s}^L, b_{v,s}^U] | \forall s \in S\} \quad (7)$$

Similarly, if importance weight is associated to every criterion $s \in S$, a consensual rough set of importance weights can also be obtained as follows:

$$R(W_s) = \{[w_s^L, w_s^U] | \forall s \in S\} \quad (8)$$

where w_s^L and w_s^U are respectively the lower limit and upper limit of the weight rough number $R(W_s)$.

Then, overall group consensus on the car $v \in V$ can be expressed by rough number $R(v) = [M_v^L, M_v^U]$. The mathematical models are formulated as follows:

$$M_v^L = \min \left(\frac{\sum_{s \in S} w_s b_s^L}{\sum_{s \in S} w_s} \right) \quad (9a)$$

$$M_v^U = \max \left(\frac{\sum_{s \in S} w_s b_s^U}{\sum_{s \in S} w_s} \right) \quad (9b)$$

$$s.t \ w_s^L \leq w_s \leq w_s^U, \forall s \in S$$

Finally, a non-deterministic ranking method is used to identify the preference relation of cars represented by the rough numbers $R(v) = [M_v^L, M_v^U]$. Let note $R(v_i) = [M_i^L, M_i^U]$ and $R(v_j) = [M_j^L, M_j^U]$ the rough numbers representing overall group consensus on the car v_i and v_j . The preference relation between cars v_i and v_j is defined through computing the dominating degree between their corresponding rough numbers $R(v_i)$ and $R(v_j)$ as follows:

$$d(R(v_i), R(v_j)) = \begin{cases} 1 & \text{if } M_j^U \leq M_i^L \\ -1 & \text{if } M_i^U \leq M_j^L \\ (M_i^U + M_i^L - M_j^U - M_j^L) / (M_i^U - M_i^L + M_j^U - M_j^L) & \text{others} \end{cases} \quad (10)$$

where $d(R(v_j), R(v_i)) = -d(R(v_i), R(v_j))$. The preference relations can be classified as follows:

If $d(R(v_i), R(v_j)) \geq \varepsilon$, v_i dominates v_j distinctly.

If $|d(R(v_i), R(v_j))| < \varepsilon$, v_i is indistinctive to v_j .

where ε is the indifference threshold that is used for identifying the preference relation between cars v_i and v_j . The result of computing is represented by the preference matrix $D = (d_{ij})$, $d_{ij} = d(R(v_i), R(v_j))$, $(i, j) \in I_D \times J_D$, $I_D = \{1, 2, \dots, n\}$, $J_D = \{1, 2, \dots, n\}$. The rank of the cars according to the estimation criteria makes it possible for the designer to select the cars they are likely to analyse for the style.

3.2. Building car – characteristic line model

A car's design is the result of the work of large teams of talented and skilled designers, many of whom work for two or more of the major automobile groups. The work of designers

is highly influential in the automotive industry. Car morphological features have the ability to preserve the property of functional *homeostasis*, the same functional states, as well as the property of *homeorhesis*, the same stable course of change. These two properties represent the evolutionary view of cars. The most striking characteristic of car morphological features is not their quantitative complexity but their qualitative stability. A car can be seen as a set of characteristic lines. The characteristic lines are morphological features that represent the silhouette of a car. Figure 2 shows the silhouette of a car during the creative phase of the car's design in a real-world automotive design experience. Characteristic lines are specific forms to which designers associate certain attributes and design know-how. These lines ultimately influence many phases of a car's engineering design and manufacturing process and can even impact customer perception of the final product. The set of characteristic lines is what we consider the car's genetic endowment.

Table 1 shows the description and illustrations of seven characteristic lines (Bluntzer et al., 2015) and the comparison with the primitives (Orsborn et al., 2006) represented in Figure 3. Because of its foundation in topology and geometry, the proposed approach is qualitative and quantitative. Indeed, car style exhibits some kind of local regularity that allows customers to distinguish these seven recurrent identifiable elements. These recurrent identifiable elements have the property that Thom calls "structural stability" (Thom, 1988b). These characteristic lines are recurrent, even though the circumstances (designer, brand, country, etc.) that produce those features are not the same in quantitative terms. These characteristic lines are qualitatively repeatable.

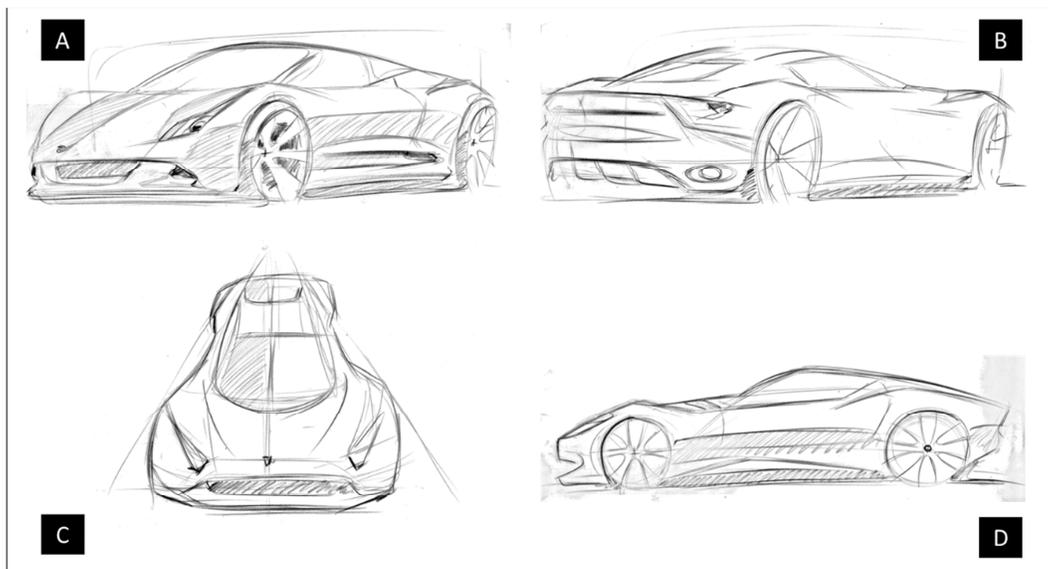
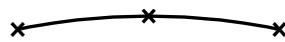
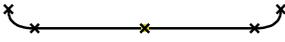


Figure 2: Silhouette of a car: 3/4 front view (A); 3/4 rear view (B); Front view (C); Lateral view (D)

Table 1. Seven characteristic lines of a car

Name	Description	Illustration	Projection plan	Primitives in (Orsborn et al., 2006)
C ₁	upper lateral profile			7,11,13,9,14,10,15,8
C ₂	lower lateral profile			3,17,4
C ₃	door profile			19
C ₄	roof profile			14
C ₅	upper grille profile			11,12
C ₆	lower bumper profile			7
C ₇	right (or left) lateral profile			19,18,6,5,3,4

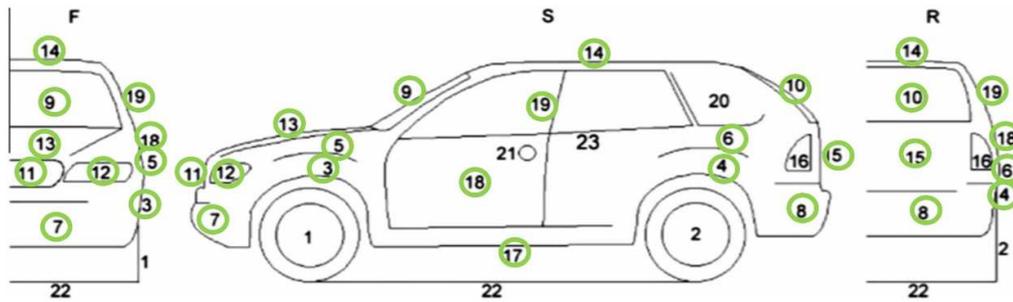


Figure 3. Comparison with the lines in (Orsborn et al., 2006). The circled number represents the primitives of characteristic lines found in (Orsborn et al., 2006)

Discontinuity and qualitative change occur in the perception of cars. Each car has its own design describing the necessary perception for the stability and the manifestation of the meaning of the concept. In this way, there is a relationship between a set of cars and the set of characteristic lines, *represented by their geometry and topology*. This relationship can be represented in the form of a matrix $M(C_k) = (\mu_{ij})$, $(i, j) \in I_M \times J_M$, $I_M = \{1, 2, \dots, n\}$, $J_M = \{1, 2, \dots, m\}$, where each line i , $i = 1, 2, \dots, n$, corresponds to a car v_i , $i = 1, 2, \dots, n$, and each

column corresponds to the coordinate of a point $p_j(x_j, y_j)$, $j = 1, 2, \dots, m$, belonging to the car's characteristic line C_k , $k \in K_C$, $K_C = \{1, 2, \dots, 7\}$.

$$M(C_k) = \begin{bmatrix} [x_{11} & y_{11}] & [x_{12} & y_{12}] & \cdots & [x_{1j} & y_{1j}] & \cdots & [x_{1m} & y_{1m}] \\ [x_{21} & y_{21}] & [x_{22} & y_{22}] & \cdots & [x_{2j} & y_{2j}] & \cdots & [x_{2m} & y_{2m}] \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ [x_{i1} & y_{i1}] & [x_{i2} & y_{i2}] & \cdots & [x_{ij} & y_{ij}] & \cdots & [x_{im} & y_{im}] \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ [x_{n1} & y_{n1}] & [x_{n2} & y_{n2}] & \cdots & [x_{nj} & y_{nj}] & \cdots & [x_{nm} & y_{nm}] \end{bmatrix} \quad (11)$$

3.3. Style-holons recognition

The general question facing the problem of style recognition is how to best organize observed CAD car characteristic lines into meaningful structures. Indeed, designers should have to organize the different characteristic lines of cars in such a way that a meaningful description of the distances between the styles of the cars is possible.

The adopted approach calculates a distance for each pair of cars, which can describe how similar the two cars are in terms of their characteristic lines. A car has been characterized by q parameters ($q = 2m$, where m is the number of points). Then every car can be represented by a point of real q -dimensional Euclidian space \mathbb{R}^q . In the Euclidean space \mathbb{R}^q , the distance between two cars can be given by the Euclidean distance (2-norm distance). However, a designer can define other derived measures of distance that can be more meaningful to the designers. Table 2 shows some distances (Anderberg, 1973; Everitt et al., 2001; Gan et al., 2007; Jambu and Lebeaux, 1978; Kaufman and Rousseeuw, 2009).

Table 2. Distances and their characteristics.

Distance	Computing measure	Characteristics
City-block (Manhattan) distance	$\delta(v_i, v_k) = \sum_{j=1}^q |\mu_{ij} - \mu_{kj}|$	It is a distance of dimension 1. It is the average difference across dimensions. It is the simplest way of computing distances between cars in a multi-dimensional space.
		The effect of single large differences between cars is dampened because the cars' dimensions are not squared.

Euclidean distance	$\delta(v_i, v_k) = \left(\sum_{j=1}^q (\mu_{ij} - \mu_{kj})^2 \right)^{1/2}$	<p>It is a distance of dimension 2. The CAD geometric distance between cars is the real distance.</p> <p>The distance between any two cars is not affected by the addition of new cars to the analysis, which may be outliers.</p> <p>In multi-dimensional space, the distances can be affected by differences in scale among the dimensions from which the distances are computed.</p>
Squared Euclidean distance.	$\delta(v_i, v_k) = \sum_{j=1}^q (\mu_{ij} - \mu_{kj})^2$	The designer can place greater weight on cars that are further apart.
Minkowski distance	$\delta(v_i, v_k) = \left(\sum_{j=1}^q |\mu_{ij} - \mu_{kj}|^p \right)^{1/p}$	<p>It is a distance of dimension p. Differences on individual dimensions as overall differences between cars are controlled by the parameter p.</p>
Chebychev distance	$\delta(v_i, v_k) = \text{Maximum} |\mu_{ij} - \mu_{kj}|$	<p>It is a distance of dimension ∞. This distance measure defines the distance between two cars as the maximum absolute difference on any one of the dimensions. The designer can use this distance if he or she wants to define two cars as different if they are different on any of the dimensions.</p>
Power distance	$\delta(v_i, v_k) = \left(\sum_{j=1}^q |\mu_{ij} - \mu_{kj}|^p \right)^{1/r}$	<p>This distance is used when designers want to increase or decrease the progressive weight that is placed on dimensions on which the respective objects are very different.</p> <p>Differences on individual dimensions are controlled by the parameter p. Overall differences between cars are controlled by the parameter r.</p>

where r and p are user-defined parameters. If r and p are equal to 2, then this distance is equal to the Euclidean distance. If $r=p$, then this distance is equal to the Minkowski distance

Then, the matrix of distances $\Delta = (\delta_{ij})$, $(i, j) \in I_\Delta \times J_\Delta$, $I_\Delta = \{1, 2, \dots, n\}$, $J_\Delta = \{1, 2, \dots, n\}$ is computed using this distance measure on the matrix $M(C_k) = (\mu_{ij})$.

$$\Delta = \begin{bmatrix} \delta_{11} & \delta_{12} & \cdots & \delta_{1j} & \cdots & \delta_{1n} \\ \delta_{21} & \delta_{22} & \cdots & \delta_{2j} & \cdots & \delta_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \delta_{i1} & \delta_{i2} & \cdots & \delta_{ij} & \cdots & \delta_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \delta_{n1} & \delta_{n2} & \cdots & \delta_{nj} & \cdots & \delta_{nn} \end{bmatrix} \quad (12)$$

The matrix of distance $\Delta = (\delta_{ij})$ is analysed to recognise the style-holons. The fact of double-headed of a style-holon implies that a style-holon must be necessarily included in a typical vertical arrangement with progressive accumulation of holon styles with respect to the distances in the $M(C_k) = (\mu_{ij})$ (12). A nested hierarchical order, called a *holarchy of styles*, can be formed. A hierarchy of style-holon is thus a holarchy. The holarchic model can be seen as an attempt to modify and modernise the perceptions of the natural hierarchy of styles. Since a style-holon is embedded in larger whole style-holons, it is influenced by and also influencing these larger style wholes. Thus, a style-holon can be considered as a whole style that is a part of a greater whole style, which at the same time contains sub-styles, of which it is composed. Style-holons can be complete in themselves, and hence can be treated as a unit. However, they are also part of a larger style-holon. Horizontal self-similarity relates to self-similarity across different styles on a given level of aggregation. Vertical self-similarity refers to self-similarity across different levels of aggregation styles.

In general, whenever the designer needs to organize data into manageable and meaningful structures, cluster analysis is of great utility. When the matrix of distance has been established then the numerical methods for finding and defining clusters based on the distance measure are termed cluster analysis. The requirement that a car style should be able to claim the membership in a style-holon, which in turn should be able to claim the membership in a style-holon, and so on, led to the use or the development of the hierarchical cluster analysis. The hierarchical clustering algorithms yield a structure of data characterized by self-embedding and self-similarity. Joining algorithm is the typical algorithm for forming the *holarchy of styles*, a nested hierarchical order. The application of the joining algorithm is to join car styles into successively larger style-holons, using the distance measure. The principle of this algorithm is the following:

Initial Step: *Each car $v \in V$ represents its own style-holon $s \in S$. Therefore, there are n singleton style-holons $s \in S$ characterised by their preference rank, which depends on the factor of variable precision β .*

General Step: *Repeat until only one style-holon is left:*

- *Find a couple of style-holons that is closest: $\min_{i,j} \delta(s_i, s_j)$*
- *Create a new style-holon s_k from the couple of style-holons (s_i, s_j)*
- *Remove s_i, s_j from the set of style-holons*

- Add the style holon s_k in the set of style-holons

At the initial step, each car represents its own style-holon. Then, the designer relaxes the criterion of the distance between two style-holons. The designer lowers its threshold regarding the decision to declare two or more car style to be members of the same style-holon. As a result, the designer links more and more cars together and aggregates larger and larger style-holons of increasingly dissimilar styles. Finally, in the last step, all style-holons are joined together.

There are various possibilities to determine a style-holon and the closest distances between style-holons. For instance, a style-holon can be represented by the centroid of contained substyle-holons (Bluntzer et al., 2014b). A linkage rule determines when two style-holons are sufficiently similar to be linked together. There are numerous linkage rules that have been proposed by researchers in cluster analysis. Table 3 shows some linkage rules, presented to the designer for the choice, from different applications in clustering (Anderberg, 1973; Everitt et al., 2001; Gan et al., 2007; Jambu and Lebeaux, 1978; Kaufman and Rousseeuw, 2009).

The hierarchical tree, representing the *holarchy of styles*, is the result of this type of clustering. The higher the level of aggregation, the less similar the car styles in the respective style-holons. The structure of the car styles is thus characterized by self-embedding and self-similarity. Self-embedding and self-similarity are thus defined by the chosen distance measure.

Table 3. Linkage rules.

Rule	Characteristics
Single linkage: nearest neighbour	<p>The distance between two clusters is determined by the distance of the two closest objects in the different clusters, i.e. by the nearest neighbours.</p> <p>This rule strings objects together to form clusters, and the resulting clusters tend to produce long chains.</p>
Complete linkage: furthest neighbour	<p>The distances between clusters are determined by the greatest distance between any two objects in the different clusters, i.e. by the furthest neighbours.</p> <p>This method forces spherical clusters with consistent diameter. This method usually performs quite well in cases when the objects actually form naturally distinct clusters.</p>
Unweighted pair-group average	<p>The distance between two clusters is calculated as the average distance between all pairs of objects in these clusters.</p> <p>This method is very efficient when the objects form natural distinct clusters. It is less affected by outliers.</p>
Weighted pair-group	<p>This method is identical to the unweighted pair-group average</p>

average	<p>method, except that in the computations, the size of the respective clusters, i.e. the number of objects contained in them, is used as a weight.</p> <p>This method is used when the cluster sizes are suspected to be irregular.</p>
Unweighted pair-group centroid	<p>The centroid of a cluster is the average point in the multidimensional space.</p> <p>In a sense, it is the centre of gravity for the respective cluster. In this method, the distance between two clusters is determined as the distance between centroids.</p>
Weighted pair-group centroid	<p>This method is identical to the previous one, except that weighting is introduced into the computations to take into consideration differences in cluster sizes, i.e. the number of objects contained in them.</p> <p>Thus, when there are or one suspects there to be considerable differences in cluster sizes, this method is preferable to the previous one.</p>
Ward's method	<p>This method uses the analysis of variance approach for computing the distances between clusters. This method attempts to minimize the Sum of Squares (SS) of any two (hypothetical) clusters that can be formed at each step.</p> <p>In general, this method is regarded as very efficient, however, it tends to create clusters of small size.</p>

4. CASE STUDY

The automotive industry in China will pay attention primarily to the Chinese car design. A French-Chinese project of Complex City concerns the styling of Chinese cars. The question of the relationship between the car's style and the cultural identity of a specific country is one of the topics addressed by this project. Country heritage seems to be a key concept that links some reoccurring features to the feeling of being home (Bluntzer et al., 2014a, 2015).

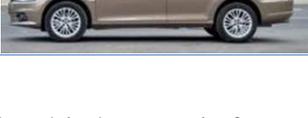
4.1. Evaluation of cars

Cars are both utilitarian from the engineering point of view and symbolic from the social point of view. The modern car retains a strong social vocation. A car can communicate the social status of the owner and translate a certain cultural distinction. During its conceptual design phase, many benchmarked car styles exist. A team of five designers $G = \{a_1, a_2, \dots, a_5\}$ is established to evaluate the benchmarked cars. These experts are from ergonomic, design, marketing, and engineering departments. A set of cars are selected and examined by the team. The study is focused on mid-range segment cars. Table 4 shows a set of selected cars $V = \{v_1, v_2, \dots, v_{20}\}$. These five members judge each car using the set of criteria $S = \{s_1, s_2\}$:

(s₁) aesthetic and (s₂) social emotion.

Table 4. Cars for the study

Car	Id	Picture
BYD F3	V ₁	
BYD L3	V ₂	
CHANGAN V3	V ₃	
CHERY E3	V ₄	
GEELY CK	V ₅	
GEELY EC7	V ₆	
GREATWALL C30	V ₇	
LIFAN MOTORS 620	V ₈	
ROEWE 550	V ₉	
ZOTYE Z300	V ₁₀	
FORD FOCUS	V ₁₁	
VOLKSWAGEN LAVIDA	V ₁₂	
BUICK EXCELLE	V ₁₃	

CHEVROLET SAIL	V14		
VOLKSWAGEN SAGITAR	V15		
VOLKSWAGEN JETTA	V16		
NISSAN SYLPHY	V17		
CHEVROLET CRUZE	V18		
VOLKSWAGEN SANTANA	V19		
VOLKSWAGEN BORA	V20		

A judgment set $P_{v,s} = \{p_1, p_2, \dots, p_5\}$, with five ordered judgments is formed for each couple (car, criterion). For instance, for the car BUICK EXCELLE, the judgment set (equation 1) based on (1) aesthetic and (2) social emotion criteria are respectively $P_{13,1} = \{6,7,8,8,8\}$ and $P_{13,2} = \{7,7,8,8,8\}$. The lower approximation $\underline{Apr}^\beta(p_i)$ and the upper approximation $\overline{Apr}^\beta(p_i)$ for the judgments $p_i \in P_{13,1}$ computed from equations 2a and 2b are shown respectively in Table 5 and Table 6.

Table 5. Lower approximation for judgment set $P_{13,1}$

Judgment p_i	β		$\underline{Apr}^\beta(p_i)$		
$p_1 = 6$	0	6			
	0,5	6			
	1	6			
$p_2 = 7$	0		7		
	0,5	6	7		
	1	6	7		
$p_3 = 8$	0			8	8
	0,5		7	8	8
	1	6	7	8	8
$p_4 = 8$	0			8	8
	0,5		7	8	8

	1	6	7	8	8	8
$p_5 = 8$	0			8	8	8
	0,5		7	8	8	8
	1	6	7	8	8	8

Table 6. Upper approximation for judgments in $P_{13,1}$

Judgment p_i	β	$\overline{Apr}^\beta(p_i)$				
$p_1 = 6$	0	6				
	0,5	6	7			
	1	6	7	8	8	8
$p_2 = 7$	0		7			
	0,5		7	8	8	8
	1		7	8	8	8
$p_3 = 8$	0			8	8	8
	0,5			8	8	8
	1			8	8	8
$p_4 = 8$	0					
	0,5			8	8	8
	1			8	8	8
$p_5 = 8$	0			8	8	8
	0,5			8	8	8
	1			8	8	8

The judgment sets (Table 5 and Table 6) are converted into a rough number form through the calculation of lower approximation and upper approximation. From the equation 3, a judgment p_i is represented by a rough number $R(p_i)$ defined by its lower limit p_i^L and upper limit p_i^U . The judgment set is transformed into a rough judgment set. The rough judgment sets $R(P_{13,1})$ is computed from the equation 4 for three values of the factor of variable precision β (Table 7).

Table 7. The rough judgment sets $R(P_{13,1})$

Judgment p_i	β	Lower limit p_i^L	Upper limit p_i^U
$p_1 = 6$	0	6,000	6,000
	0,5	6,000	6,481
	1	6,000	7,354
$p_2 = 7$	0	7,000	7,000
	0,5	6,481	7,737
	1	6,481	7,737
$p_3 = 8$	0	8,000	8,000
	0,5	7,737	8,000
	1	7,354	8,000
$p_4 = 8$	0	8,000	8,000

$p_5 = 8$	0,5	7,737	8,000
	1	7,354	8,000
	0	8,000	8,000
	0,5	7,737	8,000
	1	7,354	8,000

The degree of consensus of the group designers $G = \{a_1, a_2, \dots, a_5\}$ on the evaluation of the car $v_{13} \in V$ with the criterion $s_1 \in S$ is computed using the equation 6. Table 8 shows the degree of consensus of the group designers $R(B_{13,1})$ for three values of the factor of variable precision β . The degree of consensus of the group designers $G = \{a_1, a_2, \dots, a_5\}$ on the evaluation of every car $v \in V$ with the criterion $s_1 \in S$ with the factor of variable precision $\beta=0$ is shown in Table 9.

Table 8. Rough judgment sets $R(B_{13,1})$

Degree of consensus $R(B_{v,s})$	β	Lower limit $b_{v,s}^L$	Upper limit $b_{v,s}^U$
$R(B_{13,1})$	0	7,400	7,400
	0,5	7,139	7,644
	1	6,908	7,818

Table 9. Rough judgment sets for the set of cars according to the first criteria $R(B_{v,1})$

Degree of consensus $R(B_{v,1})$	$\beta = 0$		$\beta = 0.5$		$\beta = 1$	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
	$b_{v,1}^L$	$b_{v,1}^U$	$b_{v,1}^L$	$b_{v,1}^U$	$b_{v,1}^L$	$b_{v,1}^U$
$R(B_{1,1})$	5,8	5,8	5,450	6,120	4,950	6,503
$R(B_{2,1})$	4,6	4,6	4,458	4,729	3,665	5,283
$R(B_{3,1})$	4	4	3,717	4,249	3,420	4,488
$R(B_{4,1})$	6,2	6,2	5,851	6,522	5,720	6,623
$R(B_{5,1})$	4,8	4,8	4,452	5,114	4,337	5,222
$R(B_{6,1})$	6,6	6,6	6,600	6,600	6,349	6,833
$R(B_{7,1})$	6,2	6,2	5,851	6,522	5,720	6,623
$R(B_{8,1})$	5	5	4,684	5,286	4,629	5,332
$R(B_{9,1})$	6,8	6,8	6,648	6,943	6,205	7,287
$R(B_{10,1})$	6,6	6,6	6,600	6,600	6,349	6,833
$R(B_{11,1})$	6,4	6,4	5,668	7,020	5,380	7,213
$R(B_{12,1})$	5,8	5,8	5,800	5,800	4,958	6,438

$R(B_{13,1})$	7,4	7,4	7,139	7,644	6,908	7,818
$R(B_{14,1})$	5,8	5,8	5,454	6,117	5,341	6,228
$R(B_{15,1})$	7,2	7,2	6,853	7,523	6,724	7,625
$R(B_{16,1})$	6,8	6,8	6,452	7,122	5,962	7,509
$R(B_{17,1})$	7,4	7,4	7,400	7,400	6,826	7,856
$R(B_{18,1})$	6,6	6,6	6,219	6,953	5,876	7,224
$R(B_{19,1})$	6,4	6,4	6,018	6,752	5,714	7,041
$R(B_{20,1})$	5,4	5,4	5,134	5,641	4,895	5,813

The consensual rough set of importance weights for the two criteria is shown in Table 10. Obviously, the group is consensual on the equality of the importance of the criteria s_1 and s_2 .

Table 10. Consensual rough set of importance weights $R(W_s)$

Degree of consensus $R(W_s)$	Lower limit w_s^L	Upper limit w_s^U
$R(W_1)$	0,5	0,5
$R(W_2)$	0,5	0,5

The overall group consensus on the car $v \in V$ expressed by rough number $R(v) = [M_v^L, M_v^U]$ (Table 11) is computed using the mathematical model (9a) and (9b).

Table 11. Consensual rough set of importance weights $R(W_s)$

Degree of consensus $R(v)$	$\beta = 0$		$\beta = 0.5$		$\beta = 1$	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
	M_v^L	M_v^U	M_v^L	M_v^U	M_v^L	M_v^U
$R(v_1)$	5,4	5,4	5,085	5,686	4,429	5,497
$R(v_2)$	4,8	4,8	4,571	5,007	4,629	5,332
$R(v_3)$	3,2	3,2	3,059	3,325	2,141	2,611
$R(v_4)$	6,1	6,1	5,787	6,388	5,436	6,503
$R(v_5)$	4,3	4,3	3,949	4,612	3,331	4,215
$R(v_6)$	6,9	6,9	6,727	7,062	6,724	7,625
$R(v_7)$	5,6	5,6	5,267	5,904	4,629	5,332
$R(v_8)$	4,6	4,6	4,442	4,743	4,037	4,346
$R(v_9)$	6,6	6,6	6,524	6,671	6,153	6,629
$R(v_{10})$	6,6	6,6	6,600	6,600	6,349	6,833
$R(v_{11})$	5,1	5,1	4,558	5,564	3,331	4,215
$R(v_{12})$	5,9	5,9	5,743	6,044	5,633	6,335
$R(v_{13})$	7,5	7,5	7,369	7,622	7,350	7,834

$R(v_{14})$	5,9	5,9	5,588	6,186	5,436	6,503
$R(v_{15})$	6,8	6,8	6,627	6,962	6,153	6,629
$R(v_{16})$	6	6	5,826	6,161	5,037	5,349
$R(v_{17})$	6,9	6,9	6,768	7,021	5,903	6,816
$R(v_{18})$	6,6	6,6	6,409	6,776	6,349	6,833
$R(v_{19})$	6,5	6,5	6,309	6,676	6,349	6,833
$R(v_{20})$	5,1	5,1	4,793	5,378	4,337	5,222

The ranking method is used to identify the preference relation of cars. Table 12 shows the ranking of cars for three values of the factor of variable precision β .

Table 12. Ranking of cars

Rank	$\beta = 0$	$\beta = 0.5$	$\beta = 1$
1	v ₁₃	v ₁₃	v ₁₃
2	v ₆	v ₆	v ₆
3	v ₁₇	v ₁₇	v ₁₀
4	v ₁₅	v ₁₅	v ₁₉
5	v ₉	v ₁₈	v ₁₈
6	v ₁₀	v ₁₀	v ₉
7	v ₁₈	v ₉	v ₁₇
8	v ₁₉	v ₁₉	v ₁₅
9	v ₄	v ₄	v ₄
10	v ₁₆	v ₁₆	v ₁₄
11	v ₁₂	v ₁₂	v ₁₂
12	v ₁₄	v ₁₄	v ₁₆
13	v ₇	v ₇	v ₂₀
14	v ₁	v ₁	v ₁
15	v ₁₁	v ₂₀	v ₂
16	v ₂₀	v ₁₁	v ₇
17	v ₂	v ₂	v ₈
18	v ₈	v ₈	v ₅
19	v ₅	v ₅	v ₁₁
20	v ₃	v ₃	v ₃

4.2. Building a car – characteristic line model

In this phase, the model for a relationship between cars and their corresponding characteristic lines is built. Singularities are used to identify the characteristic lines in car styles. The selected and evaluated cars of different brands, with their specific styles, are used

to identify and extract characteristic styling primitives. The approach for building a car – characteristic line model performs in four steps (Bluntzer et al., 2014b). The stylist space is used to identify the characteristic line of a specific style based on the observation of the styling process. Then CAD space is used to extract the characteristic lines from a CAD car model. In the first step, the car CAD model is represented by its respective blueprint. For instance, a car and its four views into the CAD space of CATIA V5 are shown in Figure 4a. An extracted profile of the lateral view represents a lateral blueprint (Figure 4b) of this car. Considering the singularities (Figure 5a), the blueprint is decomposed into primitives of *characteristic lines* for every car (Figure 5b). The CAD procedures for extracting and representing each car’s characteristic lines is shown by the schematic chart of Figure 6.

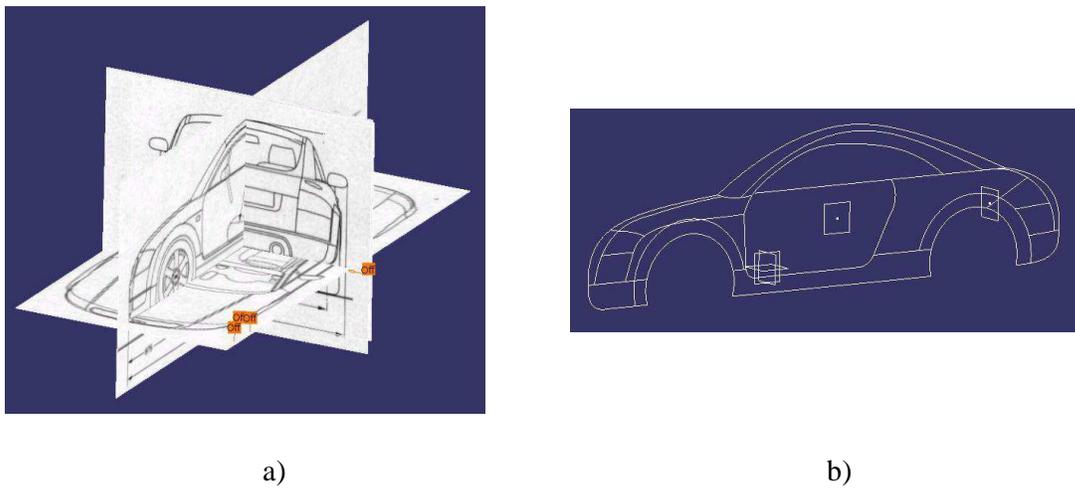


Figure 4. (a) Four views of a car; (b) extracted profile of the lateral view.

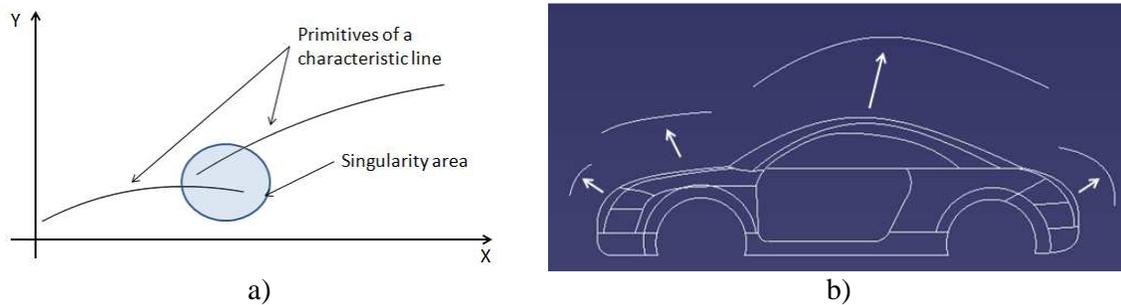


Figure 5. (a) Singularity area; (b) primitives of the characteristic line, called upper lateral profile, of a car.

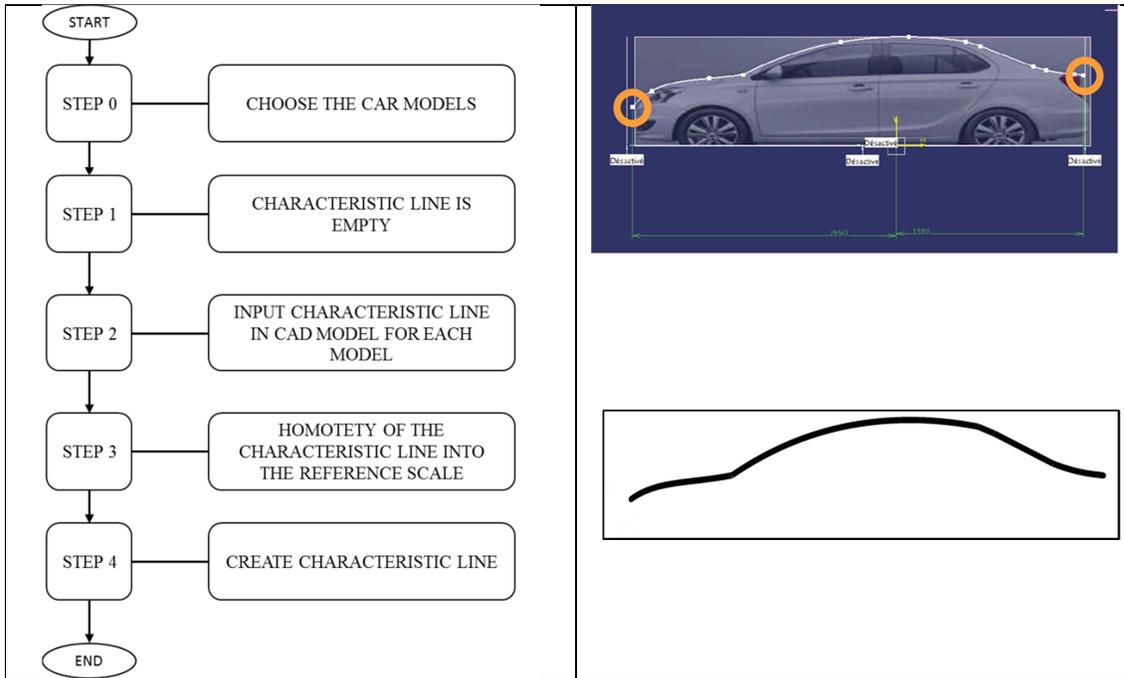


Figure 6: Procedure for extraction of characteristic lines for a car

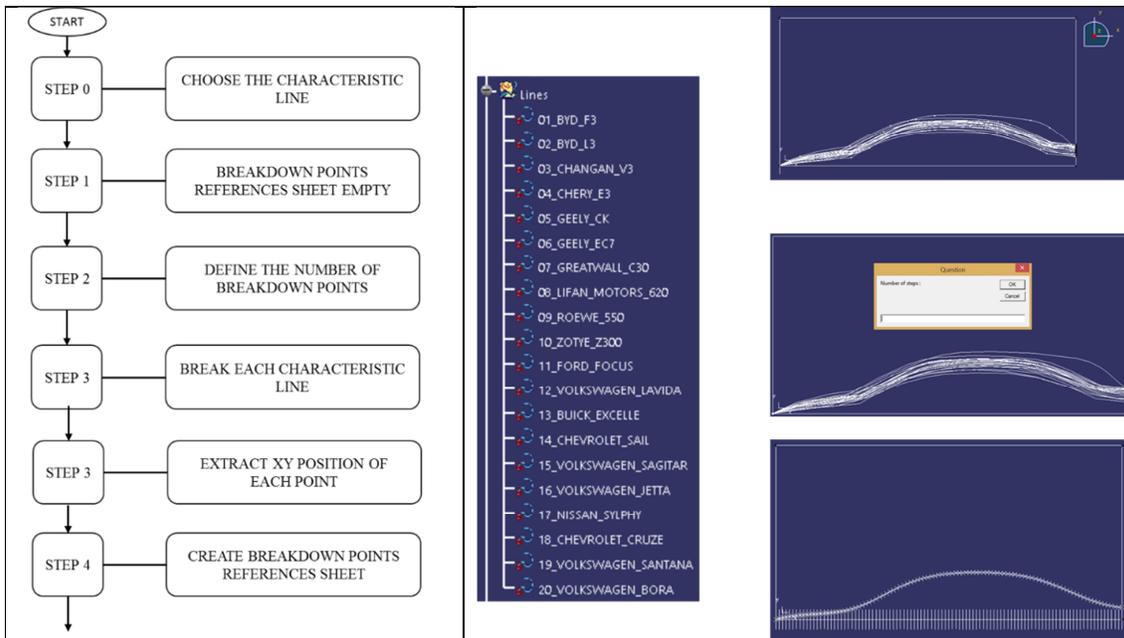


Figure 7: Procedure for characteristic point-based representation of characteristic lines

	X ₀	Y ₀	X ₁	Y ₁	X ₂	Y ₂	X ₃	Y ₃	X ₄	Y ₄	X ₅	Y ₅	X ₆	Y ₆	X ₇	Y ₇	X ₈	Y ₈	...	...	X ₉₇	Y ₉₇	X ₉₈	Y ₉₈	X ₉₉	Y ₉₉	X ₁₀₀	Y ₁₀₀
v ₁	0,00	0,00	1,00	0,25	2,00	0,48	3,00	0,67	4,00	0,84	5,00	0,98	6,00	1,11	7,00	1,21	8,00	1,30	...	...	97,00	3,84	98,00	3,67	99,00	3,53	100,00	3,43
v ₂	0,00	0,00	1,00	0,38	2,00	0,73	3,00	1,05	4,00	1,35	5,00	1,62	6,00	1,86	7,00	2,09	8,00	2,30	...	...	97,00	6,04	98,00	6,04	99,00	6,02	100,00	5,99
v ₃	0,00	0,00	1,00	0,38	2,00	0,72	3,00	1,02	4,00	1,28	5,00	1,51	6,00	1,71	7,00	1,88	8,00	2,02	...	...	97,00	5,53	98,00	5,48	99,00	5,46	100,00	5,47
v ₄	0,00	0,00	1,00	0,51	2,00	0,93	3,00	1,29	4,00	1,59	5,00	1,84	6,00	2,05	7,00	2,23	8,00	2,38	...	...	97,00	4,07	98,00	3,96	99,00	3,87	100,00	3,78
v ₅	0,00	0,00	1,00	0,21	2,00	0,42	3,00	0,62	4,00	0,83	5,00	1,03	6,00	1,22	7,00	1,42	8,00	1,60	...	...	97,00	6,70	98,00	6,65	99,00	6,61	100,00	6,56
v ₆	0,00	0,00	1,00	0,34	2,00	0,66	3,00	0,95	4,00	1,21	5,00	1,45	6,00	1,67	7,00	1,87	8,00	2,06	...	...	97,00	6,00	98,00	6,00	99,00	6,00	100,00	5,96
v ₇	0,00	0,00	1,00	0,48	2,00	0,90	3,00	1,26	4,00	1,57	5,00	1,84	6,00	2,08	7,00	2,28	8,00	2,47	...	...	97,00	3,44	98,00	3,33	99,00	3,22	100,00	3,32
v ₈	0,00	0,00	1,00	0,57	2,00	1,07	3,00	1,53	4,00	1,94	5,00	2,30	6,00	2,62	7,00	2,91	8,00	3,17	...	...	97,00	7,45	98,00	7,33	99,00	7,22	100,00	7,11
v ₉	0,00	0,00	1,00	0,23	2,00	0,44	3,00	0,63	4,00	0,80	5,00	0,96	6,00	1,11	7,00	1,25	8,00	1,38	...	...	97,00	4,27	98,00	4,23	99,00	4,22	100,00	4,23
v ₁₀	0,00	0,00	1,00	0,19	2,00	0,36	3,00	0,52	4,00	0,66	5,00	0,79	6,00	0,91	7,00	1,03	8,00	1,14	...	...	97,00	4,79	98,00	4,75	99,00	4,74	100,00	4,77
v ₁₁	0,00	0,00	1,00	0,58	2,00	1,13	3,00	1,63	4,00	2,09	5,00	2,50	6,00	2,88	7,00	3,21	8,00	3,53	...	...	97,00	8,67	98,00	7,69	99,00	6,64	100,00	5,58
v ₁₂	0,00	0,00	1,00	0,47	2,00	0,92	3,00	1,33	4,00	1,71	5,00	2,04	6,00	2,33	7,00	2,59	8,00	2,81	...	...	97,00	7,07	98,00	6,89	99,00	6,68	100,00	6,46
v ₁₃	0,00	0,00	1,00	0,31	2,00	0,60	3,00	0,89	4,00	1,17	5,00	1,45	6,00	1,71	7,00	1,96	8,00	2,20	...	...	97,00	6,49	98,00	6,45	99,00	6,39	100,00	6,33
v ₁₄	0,00	0,00	1,00	0,46	2,00	0,89	3,00	1,29	4,00	1,67	5,00	2,03	6,00	2,36	7,00	2,66	8,00	2,95	...	...	97,00	7,02	98,00	6,83	99,00	6,64	100,00	6,44
v ₁₅	0,00	0,00	1,00	0,33	2,00	0,67	3,00	1,00	4,00	1,32	5,00	1,63	6,00	1,93	7,00	2,22	8,00	2,49	...	...	97,00	7,15	98,00	7,02	99,00	6,87	100,00	6,72
v ₁₆	0,00	0,00	1,00	0,38	2,00	0,76	3,00	1,12	4,00	1,47	5,00	1,80	6,00	2,11	7,00	2,40	8,00	2,67	...	...	97,00	5,98	98,00	5,91	99,00	5,84	100,00	5,76
v ₁₇	0,00	0,00	1,00	0,20	2,00	0,40	3,00	0,60	4,00	0,80	5,00	1,00	6,00	1,20	7,00	1,40	8,00	1,60	...	...	97,00	5,42	98,00	5,26	99,00	5,08	100,00	4,91
v ₁₈	0,00	0,00	1,00	0,37	2,00	0,71	3,00	1,04	4,00	1,34	5,00	1,63	6,00	1,89	7,00	2,14	8,00	2,37	...	...	97,00	6,84	98,00	6,75	99,00	6,65	100,00	6,55
v ₁₉	0,00	0,00	1,00	0,44	2,00	0,86	3,00	1,27	4,00	1,65	5,00	2,01	6,00	2,35	7,00	2,66	8,00	2,96	...	...	97,00	6,74	98,00	6,61	99,00	6,49	100,00	6,36
v ₂₀	0,00	0,00	1,00	0,30	2,00	0,59	3,00	0,89	4,00	1,18	5,00	1,46	6,00	1,73	7,00	1,99	8,00	2,23	...	...	97,00	6,50	98,00	6,41	99,00	6,31	100,00	6,21

Figure 1: Matrix car-points in characteristic line

This relationship between the set of cars and the set of characteristic lines is represented in the form of a matrix $M = (\mu_{ij})$, $(i, j) \in I_M \times J_M$, $I_M = \{1, 2, \dots, n\}$, $J_M = \{1, 2, \dots, m\}$, where each line i , $i = 1, 2, \dots, 20$, corresponds to a car v_i and each double column j , $j = 1, 2, \dots, m$ corresponds to the coordinates of a point $p_j(x_j, y_j)$ (Figure 7) belonging to car's characteristic line C_i (*upper lateral profile*), considered by the designer. The designer can vary the number of characteristic points. Figure 8 shows the matrix *car-points in the characteristic line*.

4.3. Style-holons recognition

From the proposed distance measures, the designer has chosen the Euclidian distance. Then, the matrix of distances $\Delta = (\delta_{ij})$, $(i, j) \in I_\Delta \times J_\Delta$, $I_\Delta = \{1, 2, \dots, 20\}$, $J_\Delta = \{1, 2, \dots, 20\}$, is computed using this distance measure on the matrix $M = (\mu_{ij})$ (Figure 9).

	v ₁	v ₂	v ₃	v ₄	v ₅	v ₆	v ₇	v ₈	v ₉	v ₁₀	v ₁₁	v ₁₂	v ₁₃	v ₁₄	v ₁₅	v ₁₆	v ₁₇	v ₁₈	v ₁₉	v ₂₀
v ₁	0	12,2	7	8,56	12,5	12,4	12,4	24	11,7	10,2	45,6	22,2	16,1	31,2	23,6	19,6	7,82	17,5	22,4	14,1
v ₂	12,2	0	9,23	12,7	6,09	5,15	16,3	13,5	20,4	7,34	36,4	12,4	8,59	21,2	14	9,58	5,31	8,91	11,7	6,68
v ₃	7	9,23	0	10,6	8,47	8,83	15,6	19,9	14,6	11,2	41,4	18,4	12,1	28,3	19,7	17,4	6,37	13,3	19,5	10,1
v ₄	8,56	12,7	10,6	0	15,9	15,3	5,44	25,6	9,93	13,5	47,9	24,5	19,4	32,9	26,2	20,8	10,5	20,5	23,4	17,3
v ₅	12,5	6,09	8,47	15,9	0	3,34	19,9	13,1	21,6	8,51	34,8	11,2	6,32	20,9	12,4	10,7	6,16	6,63	12,5	4,36
v ₆	12,4	5,15	8,83	15,3	3,34	0	19,1	12,1	21,9	7,69	34,1	10,5	5,95	19,9	11,7	9,18	5,62	5,92	11,2	4,27
v ₇	12,4	16,3	15,6	5,44	19,9	19,1	0	28,7	11,6	16	51,1	27,7	23	35,2	29,5	23,2	14,2	24,3	25,9	21,2
v ₈	24	13,5	19,9	25,6	13,1	12,1	28,7	0	33,3	16,9	24	3,59	9,19	10,2	3,81	7,97	17	7,48	5,35	10,9
v ₉	11,7	20,4	14,6	9,93	21,6	21,9	11,6	33,3	0	20,2	55,2	31,8	25,9	41,1	33,4	29	16,9	27,2	31,6	23,6
v ₁₀	10,2	7,34	11,2	13,5	8,51	7,69	16	16,9	20,2	0	38,9	15	11,1	22,5	16,4	11	5,74	11,9	14,2	9,57
v ₁₁	45,6	36,4	41,4	47,9	34,8	34,1	51,1	24	55,2	38,9	0	25,6	31,5	19,4	23,6	29,8	39,3	29,2	27	33,3
v ₁₂	22,2	12,4	18,4	24,5	11,2	10,5	27,7	3,59	31,8	15	25,6	0	7,44	11,1	2,73	6,81	15,3	5,93	5,3	8,95
v ₁₃	16,1	8,59	12,1	19,4	6,32	5,95	23	9,19	25,9	11,1	31,5	7,44	0	17,8	8,76	9,12	10,1	3,69	10,1	3,05
v ₁₄	31,2	21,2	28,3	32,9	20,9	19,9	35,2	10,2	41,1	22,5	19,4	11,1	17,8	0	10	12,5	24,4	16	10	19,4
v ₁₅	23,6	14	19,7	26,2	12,4	11,7	29,5	3,81	33,4	16,4	23,6	2,73	8,76	10	0	8,23	16,8	6,75	6,46	10,5
v ₁₆	19,6	9,58	17,4	20,8	10,7	9,18	23,2	7,97	29	11	29,8	6,81	9,12	12,5	8,23	0	12,6	8,24	3,62	9,58
v ₁₇	7,82	5,31	6,37	10,5	6,16	5,62	14,2	17	16,9	5,74	39,3	15,3	10,1	24,4	16,8	12,6	0	11,1	15,2	7,93
v ₁₈	17,5	8,91	13,3	20,5	6,63	5,92	24,3	7,48	27,2	11,9	29,2	5,93	3,69	16	6,75	8,24	11,1	0	8,61	4,44
v ₁₉	22,4	11,7	19,5	23,4	12,5	11,2	25,9	5,35	31,6	14,2	27	5,3	10,1	10	6,46	3,62	15,2	8,61	0	11
v ₂₀	14,1	6,68	10,1	17,3	4,36	4,27	21,2	10,9	23,6	9,57	33,3	8,95	3,05	19,4	10,5	9,58	7,93	4,44	11	0

Figure 9: Matrix of distances

In order to form the *holarchy of styles*, a nested hierarchical order, the average linkage cluster technique is used in this case study. This technique determines the admission of a car into a style-holon based on the average of the distances of that car style with the other car styles already in the style-holon. This technique eliminates the possibility of a car style joining a style-holon simply because it has a low level of distance with one of the car styles already in the style-holon. The tree plot represents the style-holon formation (Figure 10). In these plots, the horizontal axis denotes the linkage distance, and the intensity of colour

denotes the strength of the relationship between the cars in a style-holon. Thus, for each node in the tree where a new style-holon is formed, the designer can read off the criterion distance at which the respective car styles are linked together into a new, single style-holon. In addition, the variation in the colour intensity indicates the variation in the levels of style-style holons. The structure of the tree is characterized by the horizontal self-similarity as well as the vertical self-similarity (Figure 11).

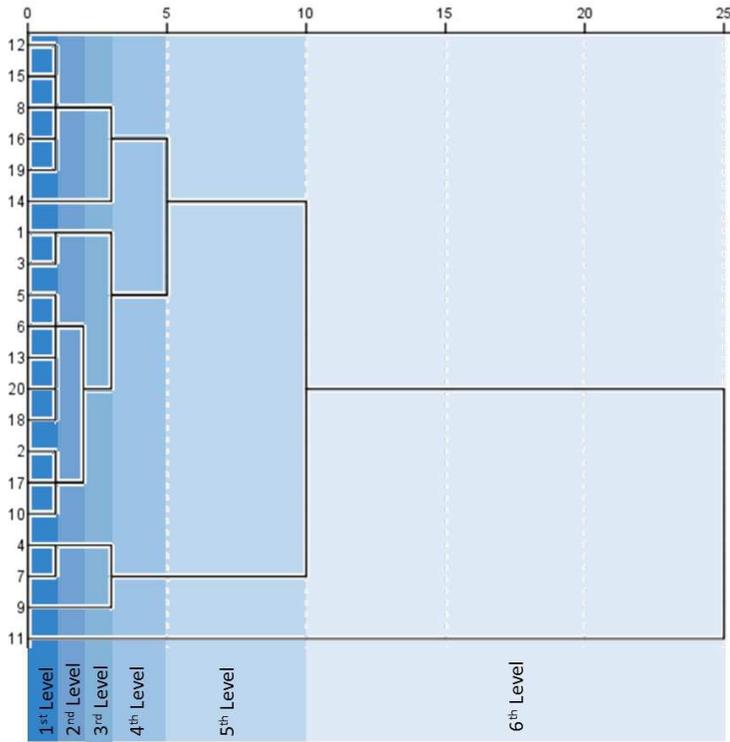


Figure 10: Hierarchy of styles

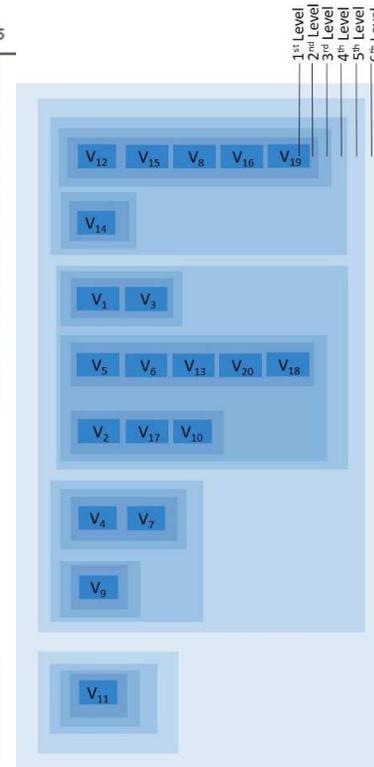


Figure 11: Self-embedding.

When a car's CAD data contains a clear structure in terms of cars that are similar to each other from the style point of view, then this structure will be reflected in the hierarchical tree as distinct branches (representing a style-holon). As a result of a successful analysis with the joining method, the designer is able to detect branches and interpret those branches as holon of similar cars. From a macroscopic examination of the tree, six levels of style-holon have been found (Figure 10, Figure 11). The property of self-embedding of style-holons is shown in Figure 11. Thus, a style-holon is a whole, that contains sub-styles of which it is composed, and at the same time, a style-holon is a part of a greater style-holon. Figure 12 shows the multi-scale car styles and the preference relation of cars in this style-holon using the results from ranking (Table 12) for $\beta=0.5$.

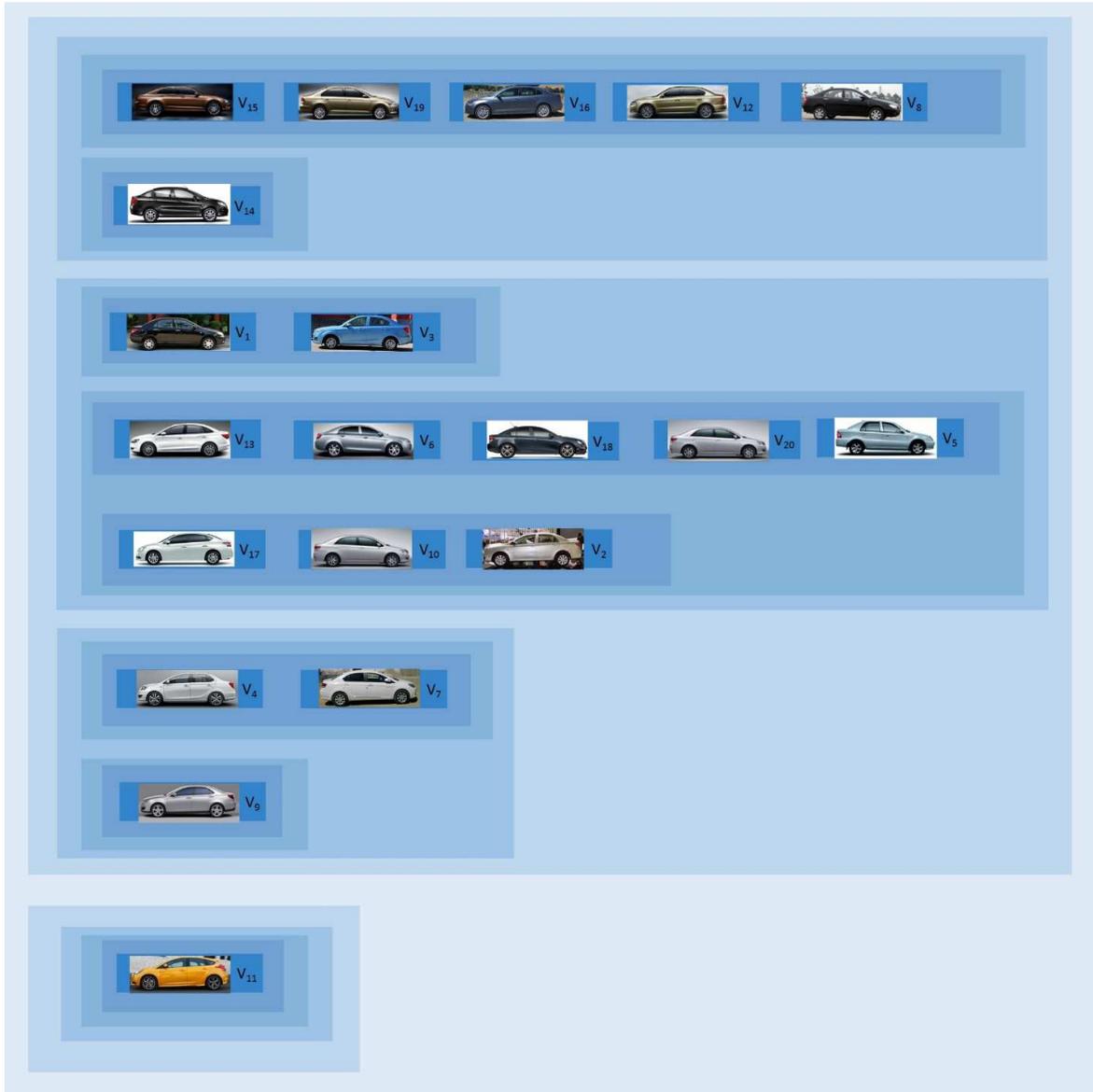


Figure 12: Ranked of cars in style-holons

Thus, the first style-holon of the fourth level characterizes mostly VOLKSWAGEN cars. VOLKSWAGEN cars are endowed with a stability of membership (Table 13). The second style-holon of the fourth level is characterized by cars from different brands, also known as a mixed style-holon (Table 14). The third style-holon of the fourth level is comprised of only Chinese cars. Chinese cars and the preference relation of cars in this style-holon using the results from ranking (Table 12) for $\beta=0.5$ are shown in Table 15. The fourth style-holon of the fourth level is exceptional (Table 16). This style-holon contains exclusively the FORD FOCUS car, and at the same time, this style-holon is a part of overall style-holon. The salience of FORD FOCUS arises from its particular upper lateral profile style.

Since a style-holon also contains substyle-holons, it is similarly influenced by and

influential on these style-holons. For instance, the mixed style-holon is composed of three substyle-holons (Table 14). Each style-holon enriches the other style in ways that neither could do for itself. This relationship, in which different style-holons develop and maintain each other and co-creatively facilitate a larger wholeness, is the holarchy of styles.

If the bi-directionality of style information flow and self-understanding is compromised, the style-holon can be discontinuously changed. When this occurs, the whole style may no longer recognize its dependence on the subsidiary style-holon parts, and parts may no longer recognize the organizing authority of the whole. A good example of this scenario can be found in the FORD FOCUS style-holon (Table 16).

The style-holon shows that the characteristic lines that make up a car's morphology preserve the property of functional *homeostasis*, as well as the property of *homeorhesis*. These two properties, representing the evolutionary view of cars, can be seen in the Volkswagen style-holon, Mixed Style-holon, Chinese Style-holon, and Ford Focus style-holon.

Table 13. Volkswagen style-holon (Style-holon 1 of Level 4)

Sub-Style-holon	Rank with $\beta = 0.5$	Id	Car	Picture	Upper lateral profile
1	4	v ₁₅	VOLKSWAGEN SAGITAR		
	8	v ₁₉	VOLKSWAGEN SANTANA		
	10	v ₁₆	VOLKSWAGEN JETTA		
	11	v ₁₂	VOLKSWAGEN LAVIDA		
	12	v ₁₄	CHEVROLET SAIL		
2	18	v ₈	LIFAN MOTORS 620		

Table 14. Mixed Style-holon (Style-holon 2 of Level 4)

Sub-Style-holon	Rank with	Id	Car	Picture	Upper lateral profile
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$\beta = 0.5$					
1	1	v_{13}	BUICK EXCELLE		
	2	v_6	GEELY EC7		
	5	v_{18}	CHEVROLET CRUZE		
	15	v_{20}	VOLKSWAGEN BORA		
	19	v_5	GEELY CK		
2	3	v_{17}	NISSAN SYLPHY		
	6	v_{10}	ZOTYE Z300		
	17	v_2	BYD L3		
3	14	v_1	BYD F3		
	20	v_3	CHANGAN V3		

Table 15. Chinese Style-holon (Style-holon 3 of Level 4)

Sub-Style-holon	Rank with $\beta = 0.5$	Id	Car	Picture	Upper lateral profile
1	7	v_9	ROEWE 550		
	9	v_4	CHERY E3		

2	13	v_7	GREATWALL C30		
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Table 16. Exceptional Style-holon (Style-holon 4 of Level 4)

Sub-Style-holon	Rank $\beta = 0.5$	Id	Car	Picture	Upper lateral profile
1	16	v_{11}	FORD FOCUS		

5. DISCUSSION AND CONCLUSION

Among the characteristics of the proposed approach, the following are noteworthy: *Quantitative paradigm versus qualitative paradigm*. The proposed computer-aided car style recognition approach uses two paradigms: (a) the quantitative paradigm and (b) the qualitative research paradigm. It is quantitative because the characteristic lines have been extracted and computed from a selection of comparable mid-range car CAD models. The computational research paradigm is also used to recognize the style-holons. Thus, a novelty of the paper is to consider car style as a holonic concept. The qualitative research has been characterized by concerns with the style interpretation. Style-holons are intermediate forms, providing a context for the proper functionality of the larger whole style. Thus, the Chinese style is an emergent context for the proper functionality of a whole style: *giving an identity to the Chinese brands through the creation of attractiveness and emotions*. It demonstrates how performance is moving from a focus on functional performance to a focus on emotional performance.

Stability: The proposed approach can be used to analyse a car's CAD morphologies as well as to evaluate the impact of selected characteristic lines. The car morphologies are diverse; a car exists in many styles. From our observations, the result of style-holon illustrates how the final car style depends on each brand's unique strategy. A car is a form endowed with some stability: its existence is in space and lasts for a period of time. The style-holon shows that the evolution of characteristic lines, as a car morphological feature, preserve as well as the property of functional *homeostasis*, that is same functional states, as well as the property of *homeorhesis*, the same stable course of change.

Follower versus innovation: It can help the designer to see the overarching style-holon for a particular style. A designer can evaluate whether the strategic requirement of the membership of car style in a style-holon is satisfied or not. A designer can also claim the originality of the innovation. Thus, by being aware of the geometrical and topological similarities, designers can demonstrate, prove, or highlight their creation or innovation.

Contextual selection: The proposed approach has been successfully applied to a range of cars and has a broad application to all types of car brands and styles. The selection of the cars just depends on the context and primary objectives each designer or brand.

Multi-view integration: Characteristic lines, defined as geometrical and topological elements, can provide both the designers' individual perspective to a product while also integrating external views for product modelling.

Recognition: Public recognition of the kinds of cars that a specific brand produces is an important engineering design problem. An important characteristic of a car's brand should be its clear and precise identity. Therefore, for many brands, an important specification is that of stability: *the customers should recognize the brand of the car*. At the same time, a brand must confront and deal with the problem of creation and evolution of the forms. The purpose of car's design, as Thom pointed out for the science in general, is to foresee this change of form and if possible, explain it (Thom, 1988b).

Future research work includes the following issues:

Emotional design: The paper shows that qualitative modelling and quantitative theorizing are closely linked in generating a car's unique style. The main focus for overall design is changing from designer-centric to user-centric (Fukuda, 2013). The relationship between a car's style and the style of other products related with the car, including the city and the environment, need to be well orchestrated and designed as a team (Fukuda, 2016).

Continuity versus discontinuity: The continuity or discontinuity of style in a given vehicle brand is an open research question. Related to this issue, the problem of "control factors," which impact the continuity or discontinuity, should be investigated. Therefore, a more powerful theory of car style should permit qualitative predictions. In doing so, this will allow the stylist to clearly identify the style trend and its discontinuity, ultimately revealing the social and emotional morphology of the style.

6. ACKNOWLEDGEMENTS

This work is carried out as the part of the ComplexCity project. The authors should like to thank the Shanghai University and its local government for supporting the project (National Natural Science Foundation of China, No.51205242).

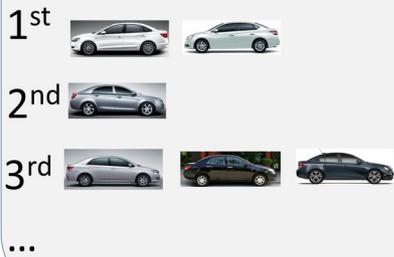
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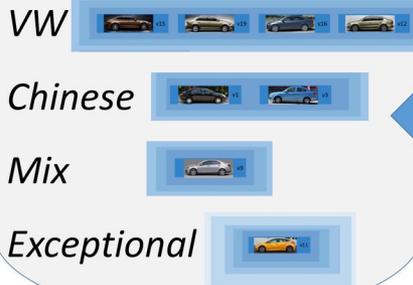
Evaluation of cars



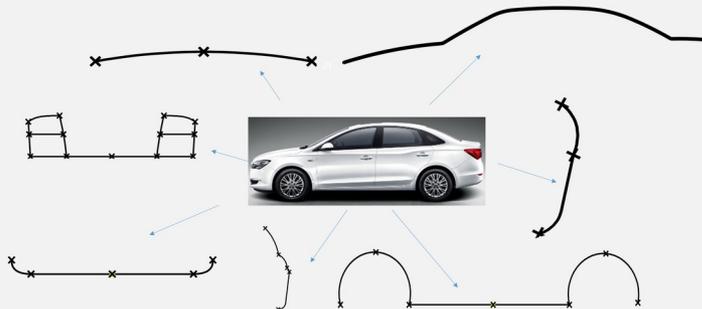
Cars



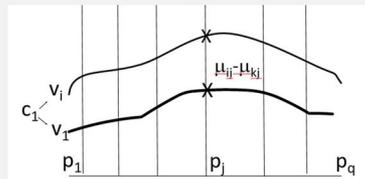
Style Holons



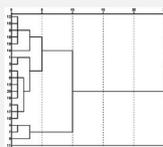
Building car – characteristic line model



Extraction of
characteristic lines
for cars



*Distance
measure*



Computing

Discovering style Holons