Understanding styling activity of automotive designers: A study of manual interpolative morphing through freehand sketching

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UNDERSTANDING STYLING ACTIVITY OF AUTOMOTIVE DESIGNERS: A STUDY OF MANUAL INTERPOLATIVE MORPHING THROUGH FREEHAND SKETCHING

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ABSTRACT
Automated morphing techniques have been proposed as a design support tool to generate novel shapes which lie between two or more polar reference images. The purpose of these techniques, employed in automated morphing systems (AMS), is to assist designers and design teams in the task of generating new shapes and finding novel form concepts. However, the usefulness of such systems for design practice may be questioned, as they significantly differ from designers' sketching processes during morphing. In this paper, we investigate the sketching processes of automotive designers in order to understand their processes of manual interpolative morphing employing freehand sketching. The objective was to understand and describe the result of their morphing processes, and relate the findings to the output of typical AMS, in order to evaluate the usefulness of AMS for design purposes. The aim was to understand how designers morph elements of product form, what types of elements are morphed, and how these elements are transformed through morphing. Results suggest that there are profound differences between manual and automated morphing. Specifically, these relate to selectivity, consistency, and completeness of morphing operations. While designers choose and transform shape based on subjective and purposeful intent, AMS lack these characteristics. These differences influence the outcome of morphing processes to a fundamental degree. Designers and design teams will be supported by these findings when considering the employment of AMS in design work. The research describes the characteristics and clarifies the potential contribution of AMS in styling activities, thus assisting the evaluation of AMS in relation to traditional, manual sketching approaches.

Keywords: automotive design, form composition, morphing techniques, perception, styling process

1 INTRODUCTION
Designers widely employ manual sketching as a tool to explore and understand new ideas and concepts for form and function in product design [1]. During sketching, the design idea is represented in the translation of the idea from abstract to concrete. According to Tovey, Porter and Newman [1], the actual process of creating design idea is usually envisaged as going on in the mind's eye and drawings as attempts to reproduce the designer's mental images.
Schön and Wiggins [2] have investigated kinds of seeing and their relationship with the design activity. They regard designing as a conversation with materials conducted in the medium of drawing, and crucially dependent on seeing. It is characterized as a reflective conversation with materials whose basic structure-seeing-moving-seeing- is an interaction of designing and discovery. Designers draw on paper, observing the evolving product of their work, employing different kinds of seeing (visual apprehensions, literal seeing), and, as this is done, discoveries are made. Features and relations are identified which cumulatively generate a fuller understanding, or 'feel for' the configuration with which designer's is working. They conclude that this involves giving attention to a process that computers are presently unable to produce.
Two types of sketching that often occur in the design process are the free, exploratory search for new design ideas, and the more focused refinement of an overall theme once a main motif is established. As noted by Akner-Koler, a divergent approach, searching for more types of solutions, is generally employed early in design processes, while a narrower but deeper exploration of variance is used once

a theme has been selected [3]. These two purposes of sketching may be compared to Goel's [4] categorization of sketching relating to, respectively, lateral transformation, where more divergence is introduced, and vertical transformation, where more convergence is introduced. Goel argues that the characteristics of the design process stem from the ill-defined nature of design problems in contrast to the well-defined problems. Secondly, he argues that sketching constitutes a particular of symbol system, which is characterized by syntactic and semantic denseness and by ambiguity, and it is the aspects of sketching which allow lateral transformation to occur. In his analysis, transformation may be either lateral or vertical, while reinterpretations occur when the meaning associated with a drawing in one episode is subsequently changed. Goel concludes that sketching is associated with preliminary design because it is a symbol system that is dense and ambiguous and consequently facilitates the lateral transformations that are an essential aspect of this phase of the design process. These divergent and convergent approaches of sketching play an important role in designers' processes of exploring the possible solution space in design work. According to Goel [4], the inherent characteristics of designers' processes of thinking and sketching – being vague, fluid, ambiguous, and amorphous – thus render them beyond the capacity of currently computational systems.

Automated morphing systems (AMS) generate form variation based on metamorphosis of form structures. It is a quantified structure strategy and it can be based on the variation of arrangement – number and dimension [5]. AMS may be categorized into two types; digital image warping techniques, and design interpolation. Digital image warping techniques employ geometrical transformation of digital images [6]. A geometrical transformation is an operation that redefines the spatial relationship between points in an image. A warp may range from something as simple as translation, scale, or rotation, to something as elaborate as a convoluted transformation [6].

Several approaches have been used for geometric transformation through interpolation (see e.g., [7, 8, 9]). These employ a number of algorithms which have been developed for image morphing (see [6]), such as, e.g., linear and polynomial interpolation, and cubic splines with natural or periodic boundaries. Wolberg [10] presents three approaches work on morphing algorithms before the development of morphing, 1) Cross-dissolve; 2) Mesh warphing; and 3) Multilevel free-form deformation (MFFD) based morphing. An example of MFFD-based morphing is given in Figure 1.

Figure 1. Multilevel free-form deformation based morphing (Source: Wolberg [6])

A pioneering work along the direction of design interpolation is the research on shape averaging [11]. Shape averaging produces a series of novel shapes between two polar base shapes. It is hypothesized that the average results are useful for predicting trends in form, or for extracting stereotypes from a group of related shapes. The technique can be used to create new forms by blending general features of existing unrelated shapes. The algorithms of shape averaging enable the extraction of mean, median and mode forms from the average shape (see [11]). Figure 2 shows the blending results between car shape and teardrop shape at different weighted averaging ratios.

Figure 2. Weighted averaging shapes from a car and the teardrop shape under rations of (a) 70/30, (b) 50/50, and (c) 30/70 (Source: Chen and Parent [11])

Designers approach to form generation is, thus, principally radically different to that of AMS. Instead of generating shapes through continuous shape merging, designers construct shape through the establishment of primary elements, which are modified and developed through iteration. In this process, the form structure, also known as gestalt, of the artifact is constructed. A product gestalt is the arrangement of parts which constitute and function as a whole product, but which is more than the sum of its parts [12]. In a product gestalt, the compositional structure may be seen as consisting of form elements on various hierarchical form structure levels, which are visually interrelated in a complex manner within and between levels (Warell [13]). Warell [13] suggests an analysis technique based on visual decomposition of these structural levels (superior, intermediate, and detail levels), which facilitates the definition of purpose, type, and visual function of form elements in a product gestalt. Critically, each element may thus be recognized, articulated and understood, in terms of how it contributes to the overall gestalt. Thus, the syntactic and semantic contribution of specific form elements may be articulated.

2 RESEARCH OBJECTIVE

Although much research has been devoted to understanding designers' sketching process (e.g., [1, 14]), no studies have been found which try to describe or understand how human designers morph between two or more polar base images using sketching (or other media or tools). Furthermore, recognition of the inability of computational systems to replicate the vagueness and ambiguity of the human sketching process (e.g., [2, 4]) has contributed to the formulation of the objective of this research: to investigate the characteristics of morphing processes of designers in actual sketching assignments in relation to morphing processes of typical AMS. The aim is to evaluate the usefulness of AMS in relation to manual sketching approaches.

The overall research question of how manual morphing through sketching is different from approaches using automated morphing systems (AMS) thus guided the investigation. Based on findings reported from previous research, three sub questions were developed, according to the following:

RQ1. The ambiguous characteristics of designers' sketching processes will lead to a natural variety in output. We refer to this phenomenon as "consistency". Thus, how do designers assess their own morphing assignments with respect to intended achievement?

RQ2. Designers choose what elements to morph rather than transforming uniformly. We refer to this phenomenon as "selectivity". Thus, we are interested in understanding what types of elements designers morph. What are the characteristics of these elements?

RQ3. Designers may morph only to a partial degree ("completeness"). How, then, are elements morphed by designers with respect to completeness?

3 METHOD

In this research, we explore the operations of form transformations employed by designers during image morphing processes using freehand sketching. We also study the characteristics of these morphing sketches in order to determine how freehand sketches differ from morphing sequences generated by automated systems. Thus, in this work, the use of the bipolar morphing technique is an experimental means to elicit, identify and categorize the types of operations employed by designers during form development. The investigation was based on two studies:

In Study 1, a total of 43 selected automotive designers in the United Kingdom, Norway, Sweden, and Malaysia completed a morphing assignment, which they were subsequently asked to assess in terms of their own morphing performance. Each designer was given the task of performing morphing sequences for five views (front, side, rear, three-quarter front, and three-quarter rear), using manual freehand sketching. In each morphing sequence, designers were asked to produce three sketches, representing the stages of 25%, 50% and 75% transformation, respectively, from the left to the right polar image, thus gradually morphing the left image to the right image in three consecutive steps. Each polar image consisted of a grayscale photograph of a production car currently available on the world market. Subsequently, each designer was given the task to assess their own morphing performance in relation to the assigned task of 25%, 50% and 75% partial morphing target achievement. In the assessment, they were asked to provide a percentage number for each of the sketches in each morphing sequence. For example, a designer who assessed their 25%-target sketch to actually be somewhere between the 25% and 50% target, may have stated 35% for the 25%-target sketch.

Study 2 consisted of three analysis parts. In parts 1 and 2, morphing sequences produced by the designers in Study 1 were analysed by a total of 10 respondents; all final year, master level product design students. Two chosen view sets (front view and three-quarter front view), each represented by five separate morphing sequences of three sketches each, by five different designers, were selected by the authors based on a heuristic quality review. Each respondent was given the task to analyze the selected sets of morphing sequences with respect to similarities and inconsistencies between the sketches and polar images of each respective morphing sequence. In part 1, respondents were asked to assess the front view set, consisting of five front view morphing sequence sketches, with respect to similarities and inconsistencies. In part 2, respondents were asked to assess the three-quarter front view set, consisting of five three-quarter front view morphing sequence sketches, with respect to similarities and inconsistencies. Polar images of the chosen morphing sequences for each part of Study 2 are illustrated in Figure 3. In each part, respondents indicated similarities and inconsistencies using coloured pencils on morphing sequence sketches, printed on A3 paper sheets. Finally, in part 3, the material produced in parts 1 and 2 was heuristically analysed by the authors with respect to form structure levels, according to Warell [13].

Part 1 (Front view):

Left polar image
(VW New Beetle)

Right polar image
(BMW 3 Series)

Part 2 (Three-quarter front view):

Left polar image
(Fiat 500)

Right polar image
(Acura RL)

Figure 3. Polar images used in part 1 and part 2, respectively, of Study 2 (brand and model identifiers were not provided to respondents)

4 FINDINGS

Results from Study 1 show that designers frequently assess their own sketches as being outside the target of the assigned task of 25%, 50% and 75% partial image morphing. As an illustration, Figure 4 presents an analysis of the subjective assessments from 19 of the 43 designers, indicating the range of assessments of sketches for each target transformation for the three-quarter front view. The analysis suggests that the range of assessments for the 25% morphing stage varies between 15% and 30%. For the 50% and 75% morphing stages, the variation is between 40% and 65%, and between 70% and 85%, respectively.

Results from Study 2, part 1, are illustrated in Figures 5 and 6. In Figure 5, inconsistencies as indicated by respondents in the set of five morphing sequences, when compared to the left and right polar base images, are illustrated. Red lines indicate inconsistencies in relation to the right base image, while blue lines indicate inconsistencies in relation to the left base image. For all Figures, numerals denote the number of inconsistencies reported for each element as indicated by respondents.

In Figure 6, similarities as indicated by respondents in the set of five morphing sequences, when compared to the left and right polar base images, are illustrated. Red lines indicate similarities in relation to the right base image, while blue lines indicate similarities in relation to the left base image.

Similarly, results from Study 2, part 2, are illustrated in Figures 7 and 8. In Figure 7, respondents have indicated inconsistencies of the set of five morphing sequences as compared to the left and right polar base images. Red lines indicate inconsistencies in relation to the right base image, while blue lines indicate inconsistencies in relation to the left base image.

Finally, in Figure 8, respondents have indicated similarities of the set of five morphing sequences as compared to the left and right polar base images. Red lines indicate similarities in relation to the right base image, while blue lines indicate similarities in relation to the left base image.

In part 3, inconsistencies and similarities as indicated by respondents in parts 1 and 2 of Study 2 were

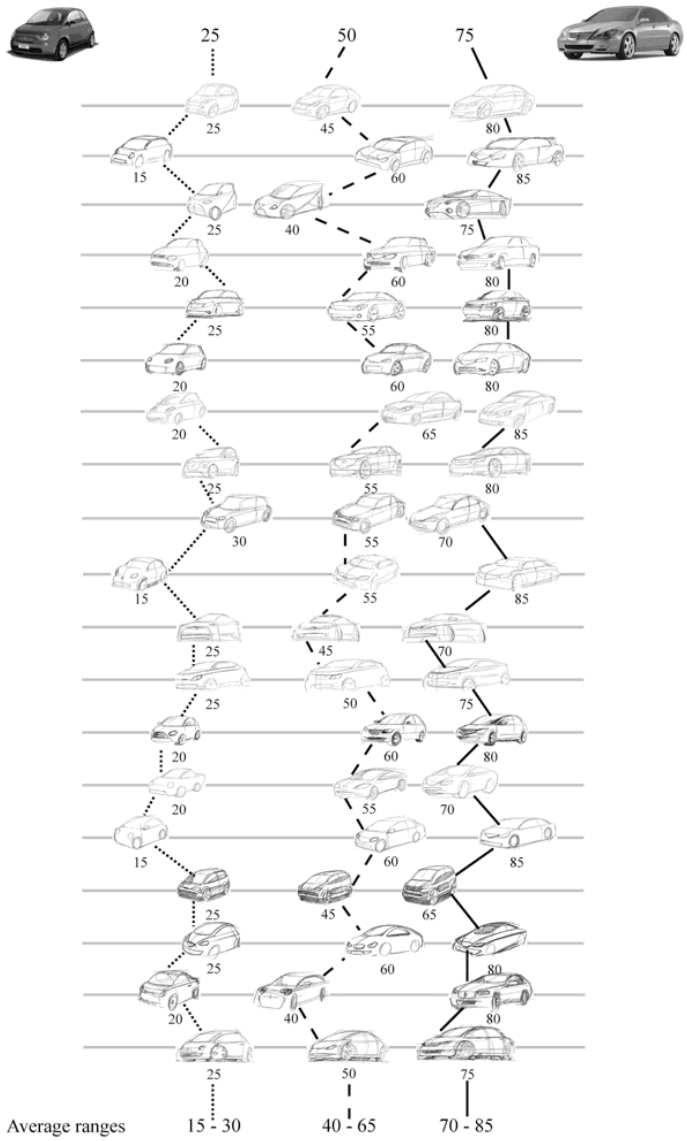

Figure 4. Compilation of designers' assessments of their own morphing achievements for the three-quarter front view, in relation to the morphing target. Average range denotes the lowest and highest assessment of designers' sketches for each morphing target

analysed with respect to form structure levels [13], based on a heuristic evaluation of all indicated elements. In the analysis, form elements indicated by respondents were decomposed and categorized according to three structural levels; Level 1 (superior level), Level 2 (intermediate level), and Level 3 (detail level). Figures 9 and 10 illustrate the analysis of form structure levels for the front view set and the three-quarter front view set, respectively.

5 DISCUSSION

In this research, we explored how designers morph between a set of two bipolar images using interpolative freehand sketching. The sketching occurring during interpolative morphing requires the designer to create a continuum of visualizations that differ mainly at the lower form structure levels. This is similar to the transformation occurring during vertical type of sketching, when the designer refines ideas on a detailed level with respect to meaning and content. This vertical sketching occurs, for example, during the stage when the designer moves from the overall to the more detailed stages in automotive concept sketching, and explores variants within a given theme [1, 15].

This research focuses on the characteristics of designers' morphing processes in relation to those of automated morphing systems (AMS). The proposed research questions investigated the morphing

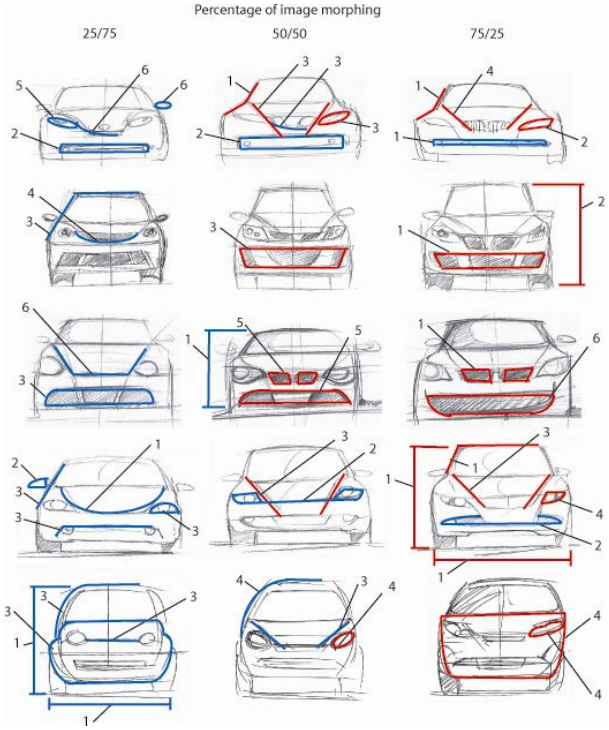

Figure 5. Inconsistencies between polar base images and front view set of five selected morphing sequences as indicated by respondents (Study 2, Part 1). Numerals denote the number of inconsistencies reported for each element as indicated by respondents.

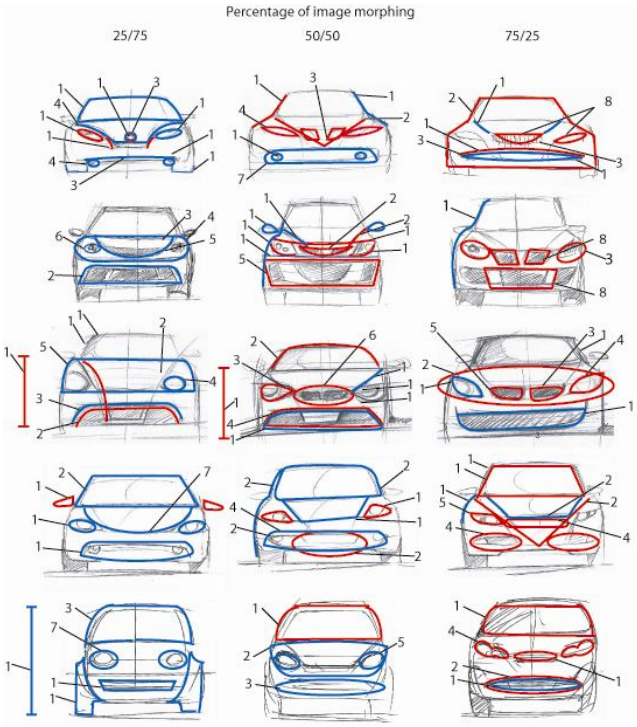

Figure 6. Similarities between polar base images and front view set of five selected morphing sequences as indicated by respondents (Study 2, Part 1). Numerals denote the number of inconsistencies reported for each element as indicated by respondents.

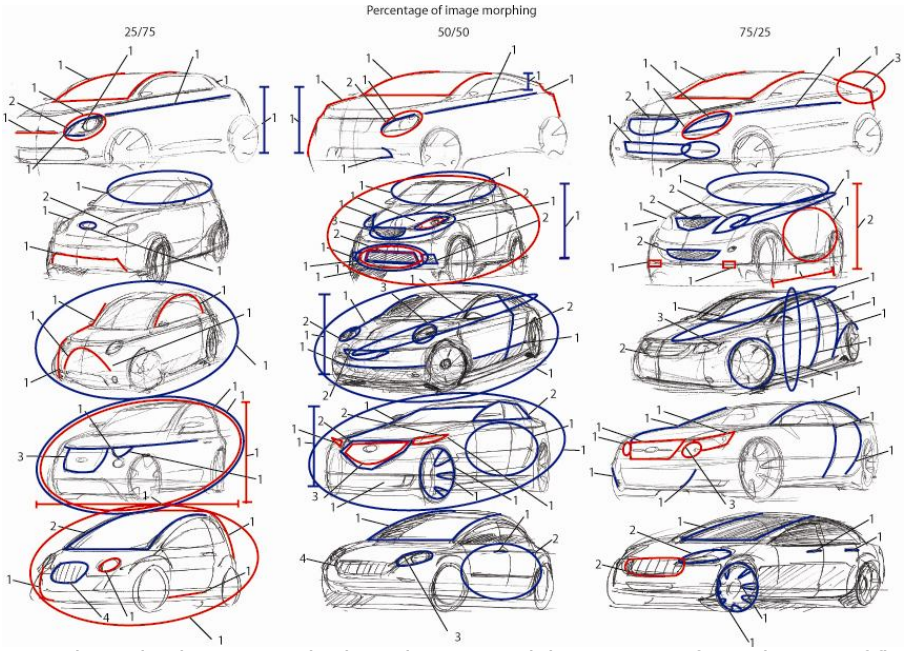

Figure 7. Inconsistencies between polar base images and three-quarter front view set of five selected morphing sequences as indicated by respondents (Study 2, Part 2). Numerals denote the number of inconsistencies reported for each element as indicated by respondents.

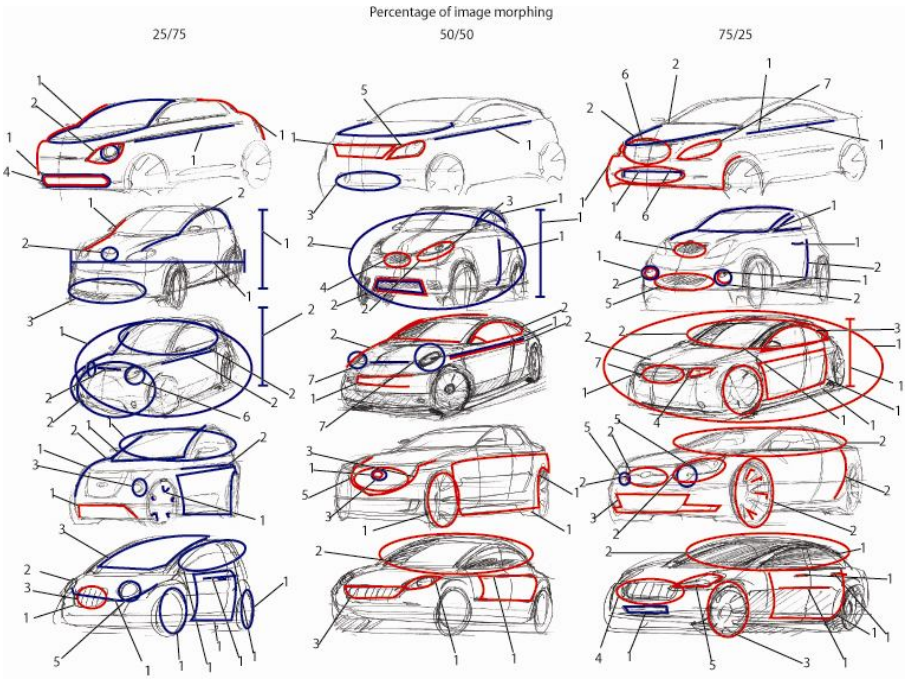

Figure 8. Similarities between polar base images and three-quarter front view set of five selected morphing sequences as indicated by respondents (Study 2, Part 2). Numerals denote the number of inconsistencies reported for each element as indicated by respondents.

process with respect to three characteristics. The first is consistency, describing the variety of output of a morphing sequence, given the same input. Secondly, selectivity, describing the uniform transformation of elements during a morphing sequence. And, thirdly, completeness, denoting the extent to which elements are partially or completely transformed throughout a morphing sequence.

For AMS, intrinsic characteristics include absolute consistency, the total absence of selectivity, and total completeness of transformations. In contrast, our findings suggest that designers' morphing processes are characterized by low consistency (a high level of variety between sets of

transformations), a high level of selectivity (some elements are transformed while others are left unattended), and a low level of completeness (elements are only partially transformed throughout the stages of a morphing sequence). This is in accordance with Goel's [4] description of the sketching process – being vague, fluid, ambiguous, and amorphous – characteristics, which are beyond the capacity of current computational systems.

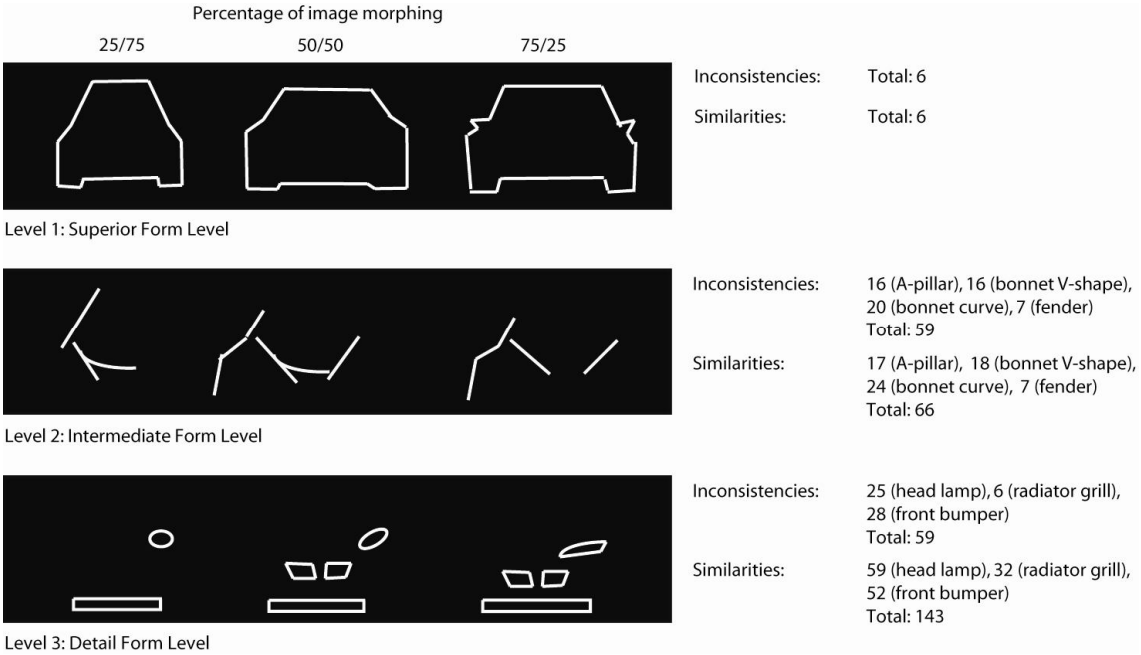

Figure 9. Analysis of form structure levels for the front view set based on heuristic evaluation of all elements indicated by respondents

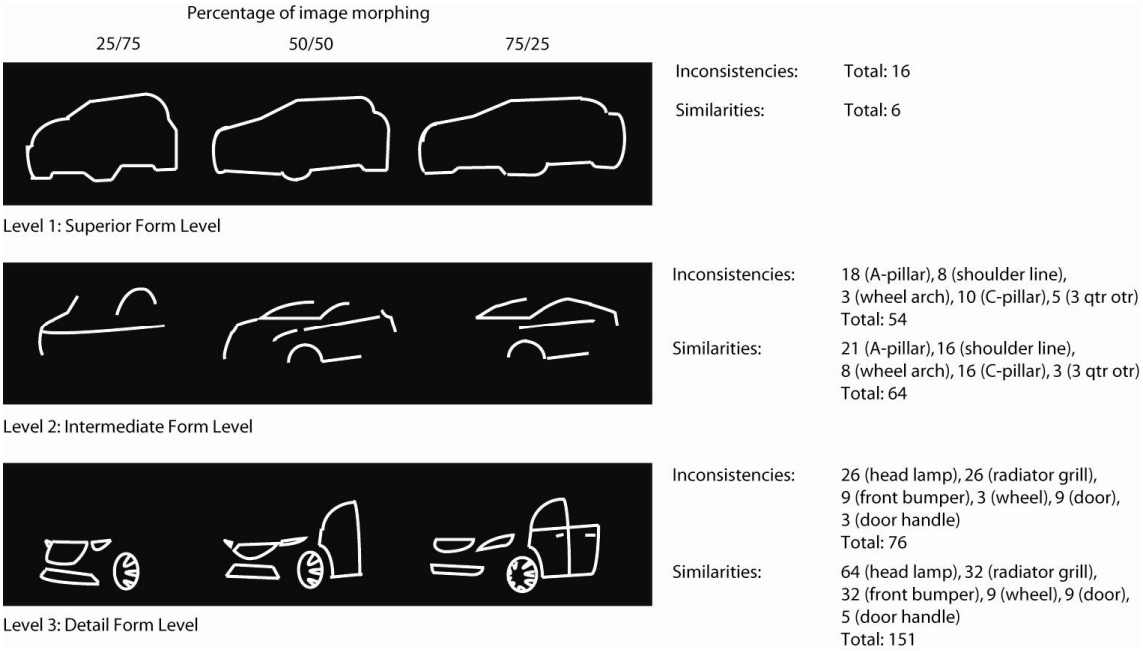

Figure 10. Analysis of form structure levels for the three-quarter front view set based on heuristic evaluation of all elements indicated by respondents

Addressing the first research question, we have shown that manual sketching is characteristically different from AMS with respect to consistency. In contrast to AMS, a designer assigned the same morphing task will not produce an identical result every time. With respect to target performance, i.e. the ability of the designer to realize intent, performance will vary considerably between designers and between assignments, as shown in this research. The introduction of ambiguity to the sketching process is, of course, a natural source of inspiration and variety. Reflective thinking, as described by Schön [16], will lead to new interpretations and present opportunities for new solutions in the process of sketching as performed by the designer. In fact, it seems the designer introduces elements which are of vertical character (i.e. divergent) in interpolative morphing processes, a characteristic which is not found in AMS. On the contrary, AMS will produce identical results time after time, given the same input. From the perspective of producing a variety of solutions, manual sketch work may thus be considered superior.

As proposed in this paper, a major difference between designers' and automated systems' approaches to morphing resides in the recognition and consideration of purpose of form elements. Designers morph through sketching on three levels of form structure: superior level, intermediate level, and detail level. According to Warell [13], form composition is constructed by visual features on all these levels. As suggested by Figures 9 and 10, utility of form elements increases with greater level of detail; hence, on the superior form level, utility is low. Our findings suggest that the amount of transformations, as represented by the number of morphing inconsistencies and similarities, increases drastically with greater level of detail, in the lower orders of form elements. For example, while the number of transformations amount to a total of 22 on the superior form level of Figure 10, it rises to 227 on the detail form level.

In response to the second research question, thus, this finding implies that designers in fact choose what elements to morph, rather than transforming uniformly. In contrast, the behavior of AMS would have yielded the same number of transformations regardless of form structure level. The type of elements selected by designers seems to be characterised by having functional purpose. As a consequence, the inability of AMS to recognize purpose renders them most useful for supporting form generation on the superior level of form. Accordingly, we suggest that automated morphing may be most beneficial for use in design work on the superior level of form generation.

On this level, the main purpose of form is to define the overall gestalt of the product. That is, its function is primarily visual, rather than functional. The visual purpose is shaped and described by the main motif, representing expressive characteristics and defining the typology of the product, a characteristic which is suggested by the work of Chen and Parent [11] (Figure 2). This finding is in contrast to designers' sketches, which suggest that most form transformation (represented by the generation of similarities and inconsistencies) occur at the intermediate and detail levels of product form.

Is utility important in sketching? It may be argued that in the initial phases of form exploration for new product design, utility is not of primary importance. Rather, the search for new stylistic themes, embodying new design formats and generating novel representations, an activity which may be far removed from the focus on utilitarian function, is of core interest. In initial phases, then, AMS may be employed as a means to generate ideas for new shapes at all levels of form composition. However, these shapes will lie in the space defined by the polar images used.

Finally, with respect to the third research question, our findings suggest that designers in fact morph only to a partial degree, exhibiting a low level of completeness in sketch transformation. This is illustrated by Figures 5 through 8. The top row of sketch transformations in Figure 5 exhibits two examples of the low level of completeness in morphing. Going from left to right, the left headlight of the leftmost sketch is only transformed in the first of the three sketches. Similarly, the line indicating the split line between the bonnet and bumper is only transformed in the first two sketches. Going from right to left, the right headlight is only transformed in the first two sketches. The same is true for the bone lines of the bonnet. All these are examples of partial morphing of form elements; a characteristic which would not be found in AMS.

6 CONCLUSIONS

In conclusion, we argue that AMS in its present form (exhibiting morphing behavior with the characteristics of absolute consistency, the total absence of selectivity, and total completeness of

transformations) should be used in an informed manner in design work. This is because AMS have several limitations in relation to manual sketching by designers. These include:

- AMS are not able to search the design space beyond the polar images employed. As such, AMS are strictly interpolative; new shapes will merely be a blend of the shapes defined by the set of polar images. Consequently, AMS are not useful for the generation of novel stylistic themes.
- AMS are unable to recognize and consider purposefulness of form. Hence, visual and utilitarian aspects of form elements are treated identically, resulting in loss of purpose. This effect is most significant at the detail level of form composition.
- AMS are absolutely consistent in the sense that an identical task will produce an identical result every time. Thus, the use of AMS will not lead to variety in solutions, unless polar images are varied. Manual sketch work will, in contrast, produce a variety in output, even if presented with the same task every time.

As a consequence, we suggest that AMS may be most useful for exploring a given theme during what Akner-Koler [3] and Goel [4] refer to as processes of convergent transformation. This typically occurs during the later stages of the styling process. How, then, may AMS be improved to become more useful for early stages of design, often characterized by divergent and explorative processes? A logical solution would be to introduce the ability of AMS to morph selectively and inconsistently, thus introducing ambiguity and variance. This would require AMS to recognize type and purpose of form elements, possibly through the use of approaches such as genetic algorithms or fuzzy logics. Systems with such characteristics are emerging in the field of form optimization, which may provide a suitable development possibility for AMS in the future.

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