Sketching and direct CAD modelling in automotive design

Michael Tovey and John Owen, Coventry School of Art and Design, Coventry University, Priory Street, Coventry CV1 5FB, UK

This paper examines two methods of computer-based car styling: texture mapping and direct computer modelling. An overview of current activity in the field precedes a comparison and evaluation of the methods within a typical framework for automobile concept design. Three case studies illustrate the direct modelling method, showing differences of computer use in each case. Further developments of texture mapping are reported, with a proposal for iterative combining of texture mapping and direct modelling. *© 2000 Elsevier Science Ltd. All rights reserved.*

Keywords: computer aided design; styling; automotive design

Most stages of the automotive design process use computer-aided design to some degree, and some now rely wholly on it. In concept design, however, at the start of the process, there is reluctance to commit wholeheartedly to computer use. Design studios that do use computers in concept design differ in how they use them; some allow stylists to model directly using CAD, and others only use electronic paint-box systems for sketching. Reasons for this reluctance are obvious: concept design depends on rapid production of design ideas, usually in the form of sketches, and most CAD techniques are comparatively time-consuming. Van Dijk[1] asserts that '. . . there are currently no CAD systems that live up to the requirements of concept design'. Many commercial software producers and researchers have attempted to remedy that. This paper examines whether combining sketches with computer models made by a stylist could quickly provide an appropriate solid model as part of the concept design stage.

1 *Current design processes in the car industry*

The industry is large, highly structured, and traditionally minded. Many long-established decision-making methods are still considered valid; crucially, the hand-over from stylist to engineer is seen as an important demarcation. Because product development requires high levels of investment,

1 **Van Dijk Casper, G C** 'New insights in computer-aided concept design' *Design Studies* 16(1) (1995) pp 62–80

www.elsevier.com/locate/destud
0142-694X/00 $ - see front matter *Design Studies* **21** (2000) 569–588
PII: S0142-694X(99)00027-7
© 2000 Elsevier Science Ltd All rights reserved Printed in Great Britain

design changes tend to be evolutionary, with new models developed from current ones. This allows specialisation within design teams and demarcation between various types of stylist and engineer to persist. In the traditional process a 3D model, fully painted and showing general surfaces, is considered vital in determining which concepts are worth development, and a small number of quarter-scale models are made by clay modellers to support this.

1.1 Historical overview of design

Conventionally, the automotive design process is structured to emphasise the demarcation between styling and engineering. Stylists are responsible for, and control, the early stages of the process and then hand over the design to engineers for analysis and making it ready for production. The structure of the styling phase is most easily described as it existed before the introduction of CAD. Design studios employ differing approaches to the concept design phase, but a typical arrangement is shown in Table 1, as described in Tovey[2].

1.2 Computer use in design

The styling process falls naturally into two parts: concept design (up to week 4) and design development (thereafter). Computers tend to be used more as styling proceeds, with greatest use after week 7. Surface proving and finite element analysis are typical areas where computer assistance is already well developed and is under further development.

Design development is a more considered process with the design less subject to radical change than in concept design where rapid changes are freely tolerated. It is concerned with optimisation and conformity to engineering and ergonomic principles. In it, design concepts develop from ill-defined proposals to fully detailed designs, and are then handed over to engineers. This stage is increasingly supported by CAD techniques.

2 **Tovey, M J** 'Intuitive and objective processes in automobile design' *Design Studies* 13(1) (1992) pp 23–41

Table 1. The stages of the styling process

Week 1	Issue of brief and product specification. Issue of package.
Week 2	Review of competition and influences. Informal discussion of concept sketches.
Week 3	Informal selection of concept sketches.
Week 4	Management review of concept proposals.
Week 7	Tape drawing or scale model presentation.
Week 10	Presentation of reworked tape drawings or scale models.
Week 18	Presentation of full size clay model.
Week 22	Re-presentation as required.
Week 26	Approval of 3D model.

1.3 CAD for stylists

Several attempts at computer aided concept design have been made independently of commercial software providers. Van Dijk[1] developed a 'Fast Shape Design' prototype to introduce designers to computer aided concept design. This concentrates on providing tools for designers that resemble conventional 2D drawing. Using input devices that mimic hand movement, users are able to review alternative concepts and to switch between views of them. The designer sketches curves onto a perspective plane, or brings them in from a library, and manipulates them into 3D position. Surfaces are then quickly built between them. Modifying a curve updates the surfaces attached to it. Most of the designers who used this prototype said that it could help their concept design process, though it needed further refinement.

Van Elsas and Vergeest[3] describe a program for quickly creating 'detail features' from an existing surface by displacing a constrained portion of it. Their intention was to enable designers to alter quickly generated surfaces by 'drawing' curves directly onto them and constructing either depressions or protrusions by deforming the surface with the curve. Displacements made in this way have flat tops parallel to the surface, with a zone of transition rounding off the form. Their prototype interface uses sliding controls to vary the displacement characteristics.

The current authors have also worked on rapid shape creation; see Owen, Tovey and Dekker[4], where a grey-scale image generates continuous variation in displacement of the surface. Motor car forms and human faces have been rapidly produced in this way. Although cars can be modelled quickly by applying a simplified and locally shaded 'cut-out' image to a surface, it is harder to shade a depth map for faces. Research to determine if stylists can hand-shade accurately enough for displacing a vehicle surface is planned. Depth mapped surfaces are also usable as base models for texture mapping, as described later in this paper. (Figures 1 and 2)

Hummels and Overbeeke[5] developed computer-modelling tools for a 'Two-handed Gesture Based Car Styling' method. The stylist wears on each hand gloves connected to a virtual space. Hand movements sketch out surfaces in the virtual space; varying tension in the hand movements controls the intensity, and thus the committedness, of the form. Adding calibrated feedback with a damped and sprung device similar to that described by Galyean and Hughes[6] may be of benefit. Here a voxel model is shaped using force-feedback arrays around a free moving Polhemus Isotrak device. The Isotrak, which provides constant positional information, is suspended by eight

3 Van Elsas, P A and Vergeest, J S M 'New functionality for computer-aided conceptual design: the displacement feature' *Design Studies* 19(1) (1998) pp 81–102

4 Owen J K, Tovey M J and Dekker K P 'From imagining to image: an examination of visual realisation of 3D forms' *CADE 97 Conference* University of Derby (1997)

5 Hummels C C M and Overbeeke C J 'Designing and testing human-computer interaction: a case study in virtual clay modelling' *Proceedings of the 31st ISATA Symposium* Düsseldorf (1998)

6 Galyean, T A and Hughes, J K 'Sculpting: an interactive volumetric modelling technique' *Computer Graphics* 25(4) (1991) pp 267–274

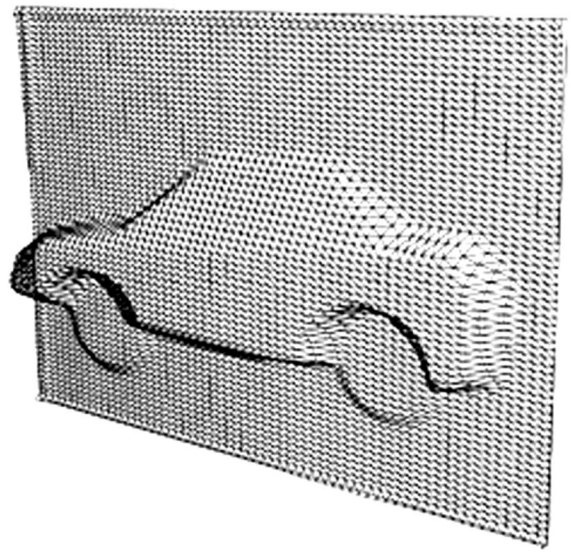

Figure 1 Surface generated by displacement mapping a greyscale image onto a plane surface

Figure 2 Texture-mapped face representations

elastic bands within a cube so that resistance can be felt while moving in space and into the virtual voxels.

Related work includes Overbeeke, Kehler, Hummels and Stappers[7], and Dijk, Vergeest and Horvàth[8].

7 Overbeeke C, Kehler T, Hummels C and Stappers P J 'Exploiting the expressiveness: rapid entry of car designers' conceptual sketches in a CAD environment' in **D Poles** (ed) *Proceedings of the 30th ISATA Symposium* Florence, Italy (1997) pp 251-258

All three students had used the Alias|Wavefront modeller before their project. Two studied part-time while continuing to work in styling studios near Coventry; the third was a full-time student. Both the part-timers were trained automotive clay modellers with fourteen years' experience between them. The full-time student had worked in a styling studio on a placement (internship) during his studies. The techniques used vary from a complete reliance on the screen image to a simultaneous clay-and-computer model approach.

In all three cases, a styling lines method was used for computer-model creation; see Owen, Tovey and Dekker[4]. B splines are placed in the three orthographic windows, and manipulated using control points to produce a network of lines in space. These lines represent major visual cues such as shut lines and feature lines. Surfaces are then produced between this network of lines and constraints such as continuity, tangency and implied curvature added. Such models may be used as finished products, or lines from the existing net or from projections onto surfaces can be used as an underlay for iterated development.

2.1.1 *Case 1: a simultaneous approach*

Computing and clay modelling facilities at the University are available throughout the day. The first student chose to model using the computer during the day and using clay in the evening. He treated the modelling process as a fully integrated task, with design decisions made in either format informing the whole development.

His experience of both clay and computer modelling led directly to this way of working. He built one clay model and a range of computer models that described the whole form. At first, his concept sketching techniques strongly influenced both model types; he made paper sketches with markers and pastels and electronic sketches with the Alias|Wavefront paint package. Later he made *ad hoc* refinements to the clay and computer models as the design developed.

He based both model types on his seating and engineering package, which also informed the under-structure of his clay 'buck'. The open-topped design meant that the buck had to accommodate a fully formed interior, so that both interior and exterior could be seen and judged together.

Because he developed the design in two formats, he could undertake some normally troublesome aspects of surface production that normally require more than a stylist's level of understanding. He resolved each problem in the more appropriate medium, and then applied the solution in the other

as time allowed. For example, proving continuity over a doubly curved surface is easier in CAD, but surface intersection and radiusing is more suited to working in clay because of tactile feedback. Rough solutions in clay can be cross-sectioned and re-imported to CAD for smoothing. (Figures 3 and 4)

2.1.2 Cases two and three: a direct modelling background.

Both students followed a specially organised part-time version of the course in conjunction with their employers, Jaguar and Rover. In this

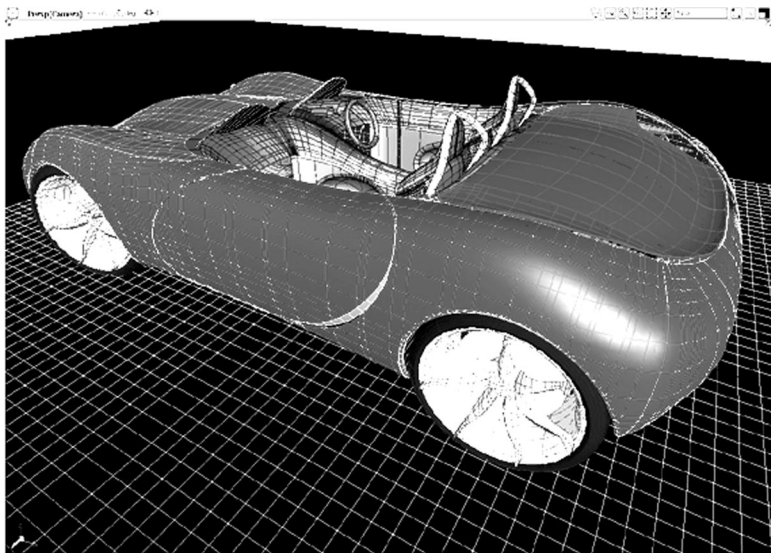

Figure 3 Snapshot from computer 3D model in the simultaneous approach

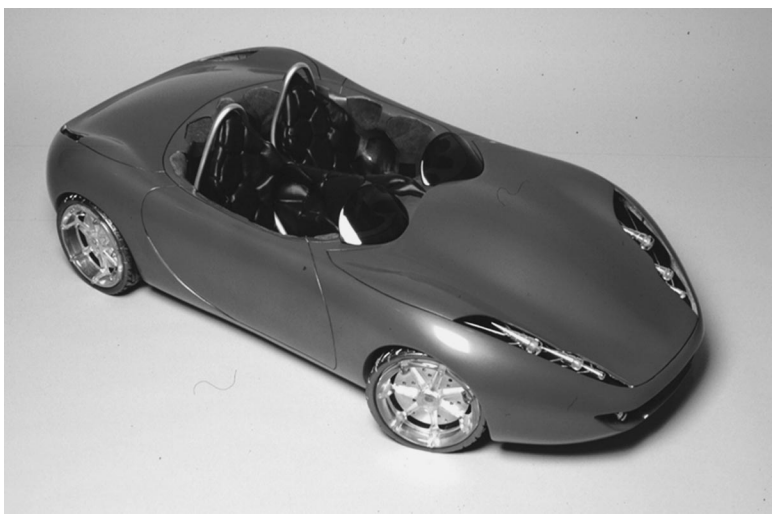

Figure 4 Photograph of finished model

course, students are asked to make as much use as possible of the facilities at their workplaces. Both of them had access to: a design studio, Alias|Wavefront software, a clay modelling studio, 3D measuring equipment, five axis milling and a fully working model shop. Despite their working in a professional environment, we assessed their work against the normal University course criteria, testing their ability to think across practice demarcations and conceptual barriers.

Though they had extensive experience of clay modelling, both students independently expressed interest in computer modelling for career development and for testing their 3D thinking skills within their projects. They felt that because their skills exceeded traditional styling capabilities they could prove that they could work successfully without heavy reliance on sketches, shortening the development cycle by crossing boundaries themselves. These aims reflect the move by some stylists into direct modelling, where a more developed concept is available faster.

Debates in design education and in styling studios reflect conflict within the industry about how much time stylists should spend in developing surfaces, and whether they should be attempting to do so. As reported in Owen[10], a few stylists prefer initial clay modelling, though most prefer initial 2D sketching. Because both students used this computer-based strategy, direct comparison is possible between clay models as sketches and working entirely at the 'tube' for concept design.

2.1.3 *Case two: no going back*

This student was confident that his clay and computer modelling skills were fully developed; he chose to make only a few 2D sketches to show others his intentions, and no 'interior dialogue' ones. He assigned two days a week to the project, though eventually his professional commitments left him only enough time to produce one finished 3D computer model before five-axis milling.

He made the basic computer model with the styling lines method and then built surfaces with a tool that enforced continuity of curvature. He checked the surfaces and the intersections with the modeller's verification tools. When he had checked the model, he had it milled in polyurethane foam.

Except where the cutter was too large, around the base of the A-post, the model was acceptably milled in one pass. The occluded A-post intersection was repaired with polyester filler and the model lightly sanded to remove evidence of the cutter path. It was then ready for painting and presentation. When the model had only primer paint on it he judged the surfaces by eye

10 **Owen J K** 'Teaching 3D appreciation and model making' *PDE 95 Proceedings of the 2nd National Conference on Product Design Education* Coventry University (1995)

and found them comparable to an equivalent clay model. He was slightly unhappy with the direction and shape of highlights on one small area of the rear C-post, and this was corrected by hand sanding and re-painting.

He then made an animation to show the vehicle in context. This used both live and computer-generated images of his vehicle being driven around the Jaguar compound in convoy with real cars. (Figs. 5 and 6)

2.1.4 Case three: a safe approach

This student's working circumstances were similar to those in case two. He sketched more conventionally, making sketches both to generate ideas and to show others his intentions. From the beginning, he intended to mill

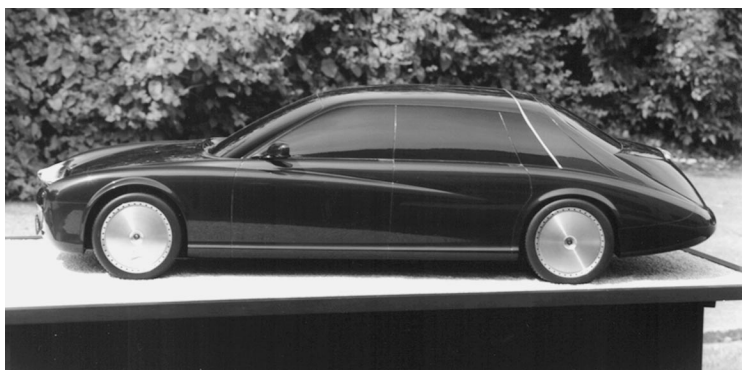

Figure 5 Finished model milled directly on 5-axis milling setup

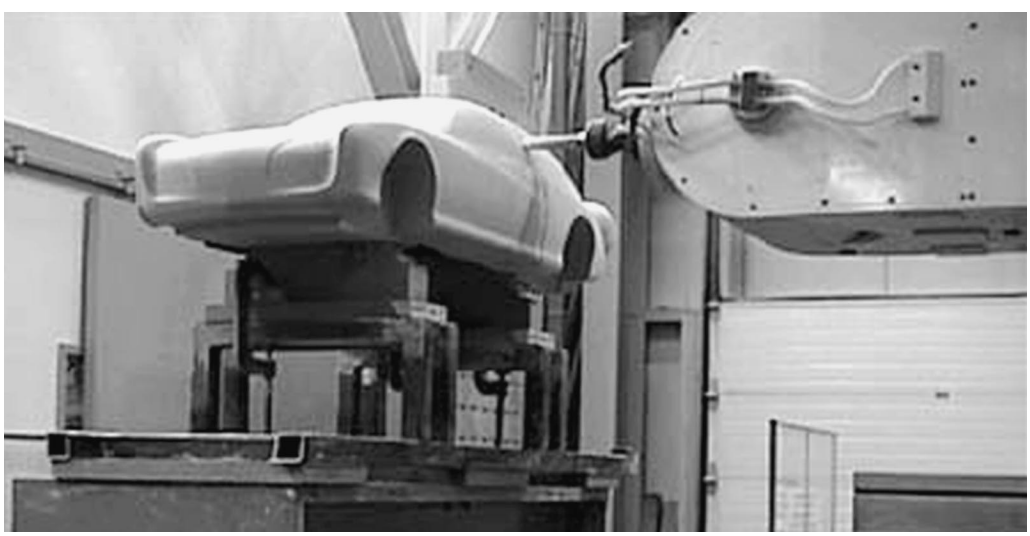

Figure 6 Milling in progress

his model in clay so that any problems with it could be amended with conventional modelling methods, and he allotted time to do this. He did most of his modelling with the computer, supporting it with concurrent detail sketching when necessary.

His design had cutout sections around the roofline, and he found a good solution by making a complete primary surface from which the cutouts would be removed after milling. The model was milled in clay, again in one pass, and he judged the surfaces to be up to standard. As he was more than happy with the finished model before doing the cutouts, he continued with the casting and painting process and finished without making major changes. (Figures 7 and 8)

2.2 *Evaluation of direct modelling*

In all three case studies, the methods used produce fewer concept ideas than the traditional styling method. This does not *per se* invalidate the direct modelling approach; there may be scope to include direct computer modelling at the concept stage. If the traditional quantity of sketching is required, the direct modelling method may be used after week three when appropriate concepts for development are chosen. This is the point in the

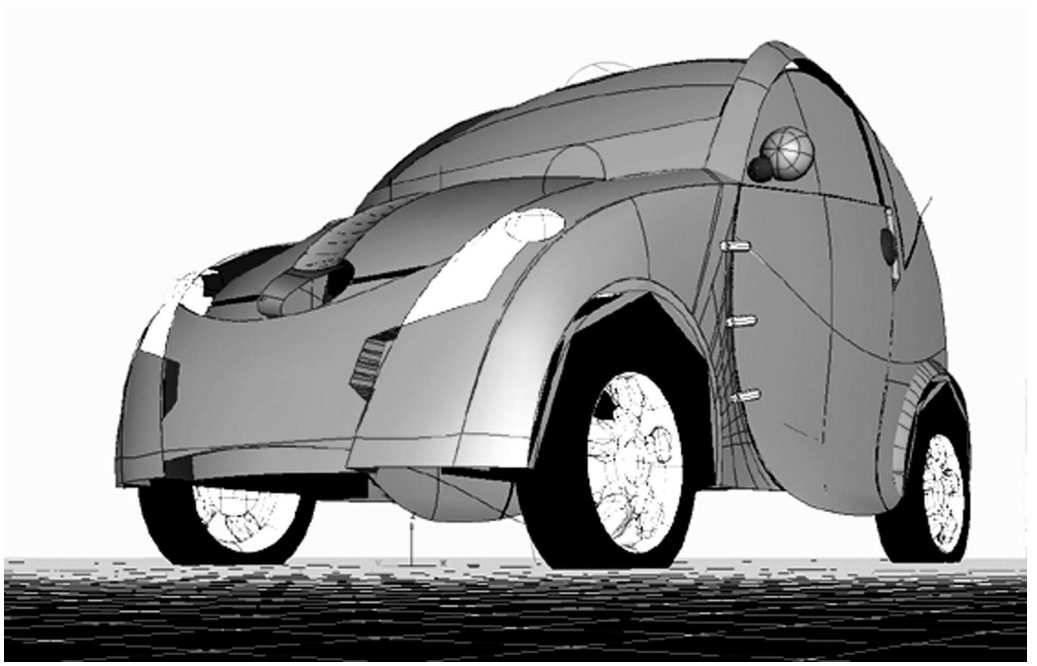

Figure 7 'Safe approach' computer model

Figure 8 'Safe approach' finished model

conventional process where rough clay or foam models may have been produced for initial 3D evaluation.

In case study one, the 'simultaneous approach' has clear advantages if applied after the initial generation of concepts on paper. Rough form resolution in the styling studio offers some verification though still allowing development of related concept designs. Choosing to advance with either computing or clay depends on the appearance chosen; for example, cross-sectional information from the clay can form a framework for an improved computer model.

In the second case study, the 'no going back' approach produces only one concept design. Only a few designers work entirely in clay or with the computer, and then only to solve problems beyond the scope of sketching; most stylists find working entirely in clay too difficult or inconvenient. Presenting designs in this way may encourage individuals to force 'their' design forward when in competition for further development by presenting a more finished design.

The 'safe approach' (case three) allows rapid production of solid models after the initial concept drawing phase. Major surfaces can be established quickly in the computer. This results in milled, but intentionally unfinished models that are later refined by hand in clay. Forward planning and a structured but mutable approach to each shape are needed in this method.

3 *Sketch-mapping*

Research on this method started at Coventry University in 1994. It had to use, to the maximum practical extent, conventional styling sketches. The intention was that models could be built directly from them as quickly and as efficiently as the sketches themselves are made. The method had to retain the spontaneous visual creativity and vitality of the sketching process. It would also overcome the limitations of a 2-dimensional representation seen from a single viewpoint by adding the third dimension in an animated presentation.

The initial version of the process used elevational drawings to make the base model. Intersecting the elevational outlines gave a coarse graphic representation of the form. It was immediately obvious that this had little resemblance to a concept sketch, and would be an inadequate substitute for one.

3.1 *Texture mapping*

The next development of the process was the use of texture mapping. This attaches the stylist's concept sketches to the base model by rendering them onto the model and then fixing them to it, so that when the form is rotated the sketch stays attached. The clay analogy would be projecting transparencies of the sketches onto a clay and painting the surface to match. The result is a simple '3-dimensional sketch' that can be rotated. See Tovey[11] for a more detailed treatment.

This is a familiar idea to design educators. Design students often cut and paste their drawings and attach them to models to evaluate their 3D characteristics. The texture mapping process gives better results, however. The technique has other uses: it can be used to create recognisable representations of people by texture mapping a photograph of a face onto a standard head form, as described in Owen, Tovey, and Dekker[4]. (Figure 9)

3.2 *The demonstrator*

These initial developments of the process were assembled into a demonstrator. This covered the process in three phases:

- orthographic pasting
- perspective pasting
- model refinement

3.2.1 *Orthographic pasting*

Line information from elevational sketches is used to create a wire model. Only package-related sketches are generally useful because they had sufficient dimensional rigour. Surface patches are built between the lines, giv-

11 Tovey, M J 'Styling and design: intuition and analysis in industrial design' *Design Studies* 13(1) (1997) pp 5–31

Figure 9 Orthographic sketches mapped onto a base model

ing a crude but effective 3D model. The sketches are then texture mapped onto the model. This retains the graphic characteristics and mannerisms of the sketches, and thus the essential thematic elements of the design. The result is a 3D 'orthographic sketch mapped model' which can be animated, rotated and scaled. The major problem with orthographic pasting is 'sketch blend', when the mapped sketches stretch over rapid changes of surface direction. (Figure 10)

3.2.2 Perspective pasting

This uses a model created as for orthographic pasting. This model is positioned twice in 3D perspective space (the perspective characteristics of which can be determined by the stylist) into suitable 3/4 views, one of the front and one of the rear. Printouts of these views are used as underlays for further stylists' sketches. Stylists like to use these accurate perspective underlays, because they know that any changes to proportions and lines will be correct. The resulting sketches are then texture mapped back onto the model from the projection points that correspond to the original perspective viewpoints. This process reduces the 'sketch blend' problem.

3.2.3 Model refinement

Perspective pasting often shows that the underlying model needs refining. Images produced in that phase provide line information for creating a 'sty-

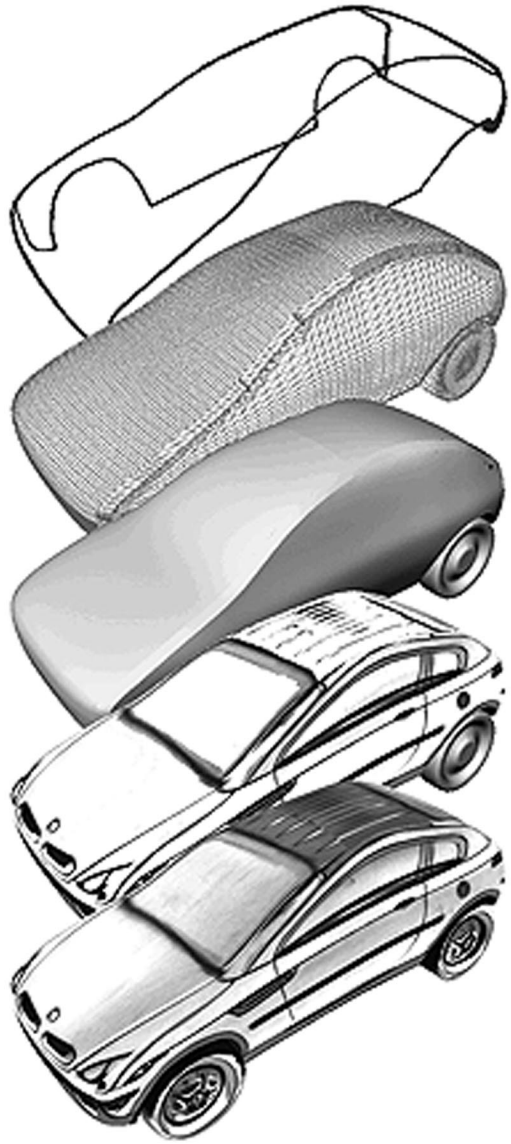

Figure 10 Orthographic sketch mapping model phases

ling lines' CAD model; see Tovey[9]. This is then surfaced to provide an improved base model.

3.3 Evaluation and verification

The demonstrator was evaluated in controlled studies with individual designers and groups from companies. The results showed that many styling departments favoured developing the method. Subsequent develop-

ment of the process has been done in conjunction with researchers at the Technical University of Delft and designers at BMW: see Overbeeke, Kehler, Hummels, and Stappers[7] for further discussion. (Figure 11)

Verification of the process was done at Coventry University in 1997. A modified perspective pasting method was used to reconstruct a Honda Prelude from photographs and line drawings in advertising material. Initial results showed a mismatch between the photographs and the drawings. Although convincing Prelude-like images were produced, a more controlled experiment was needed. Accurate photographs and line drawings of a Rover MGF sports car, given for the purpose by Rover, were used to construct a sketch-mapped model. Photographs of a real MGF were then taken, with the camera position and other characteristics such as focal length of lens, camera lens position and film back properties being carefully recorded. This data was used to construct an exact 'inverse camera' projector in Alias|Wavefront Studio, which projected the photographs onto the surfaces of the sketch-mapped CAD model. Comparison of rendered images with the actual car confirmed the usefulness and accuracy of the process.

Figure 11 Verification process, texture-mapped MGF models

3.4 Improving the process

CAD systems for designers must be user friendly. Stylists need speedy shape data input, easily specified and modified geometry, precision only where necessary, good display quality and a convenient interface, as described in Tovey[9]. Our sketch mapping technique did not meet some of these criteria. In particular, we needed convenient tools to position and apply the sketches to the form.

Our current system uses two types of input: 2D sketches or photographs, and 3D forms typically constructed from the image data. The current implementation of the process maps Silicon Graphics image files onto Open Inventor geometry; see Tovey and Harris[12]. Current developments concern two aspects of the process: perspective projection and sketch morphing.

One of the Coventry research team, Graham Harris, has created a software tool to implement the process. It has three components: a menu bar, an examiner viewer window and a texture manipulation controller.

The menu bar provides access to a number of standard features. Models can be loaded, named and saved, and other menu entries give access to functions for manipulating images and geometry.

The examiner viewer provides a 3-dimensional virtual workplace in which to create texture mapped models. The virtual camera viewpoint can be adjusted with the mouse, allowing easier manipulation and fine control of the process for attaching sketches to models.

The texture manipulation geometry controls how a sketch image is projected, positioned and scaled to fit on a surface. It consists of tools for translating, rotating and scaling images, and an orientation control tool. Converting a surface model and a set of concept sketches into a texture-mapped model for evaluation takes place in these phases:

Phase 1. Load up the 3-dimensional surface model with pre-isolated surfaces. Once loaded, it may be geometrically transformed. (Figure 12)

Phase 2. Select one of the isolated surfaces by clicking on it with the mouse. It will be highlighted, and the remaining surfaces will be shown as 'greyed-out' wire-frames.

Phase 3. Select an appropriate sketch to be attached to the highlighted surface; it will be loaded in the default position. The texture manipulation geometry tool will also be displayed. (Figure 13)

12 Tovey M J and Harris G 'Sketch mapping: concept representations for stylists' *Proceedings of the 31st ISATA Symposium* Düsseldorf (1998)

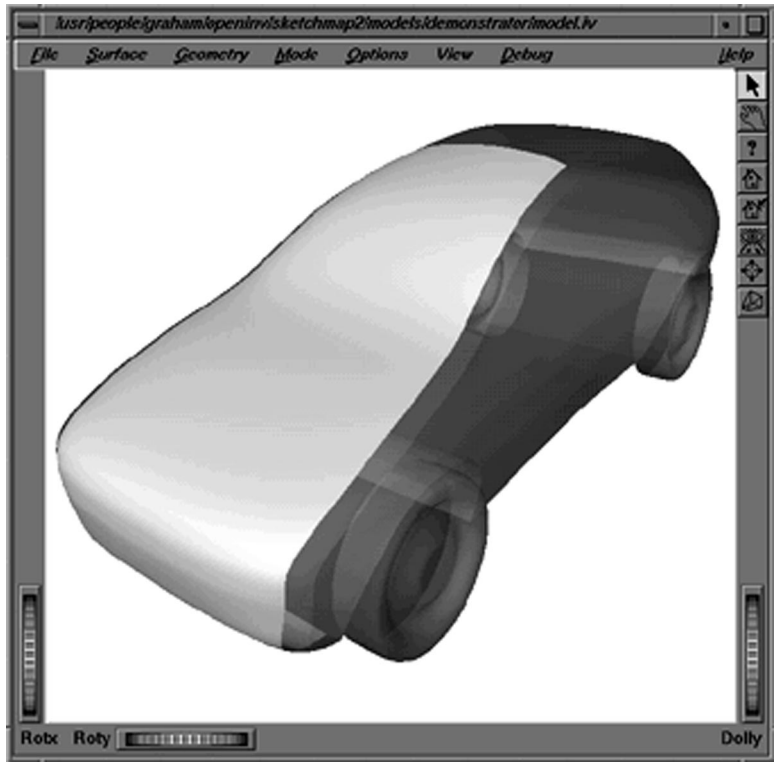

Figure 12 Front view surface isolated ready for sketch mapping

Phase 4. Using the texture manipulation geometry tool, position the sketch on the surface as desired. Typically, this process involves using the orientation control tool followed by some scaling and translation of the image. (Figure 14)

Phase 5. Repeating phases 2–4 until all the sketch images have been applied to the appropriate surfaces will result in a virtual 3-dimensional sketch, which can be viewed from any position and will appear as a sketched image whatever the viewpoint.

Further developments currently in hand concern two aspects of the process. The perspective projection aspect investigates attaching 3/4 view sketches to the model in true perspective, as in the demonstrator. Additionally, sketch morphing is being developed to overcome the minor mismatch problems that can occur at the junctions of sketches that have been applied. (Figure 15)

This advanced sketch mapping implementation appears significantly useful. It is quick and comfortable, and is acceptable for use in the concept design

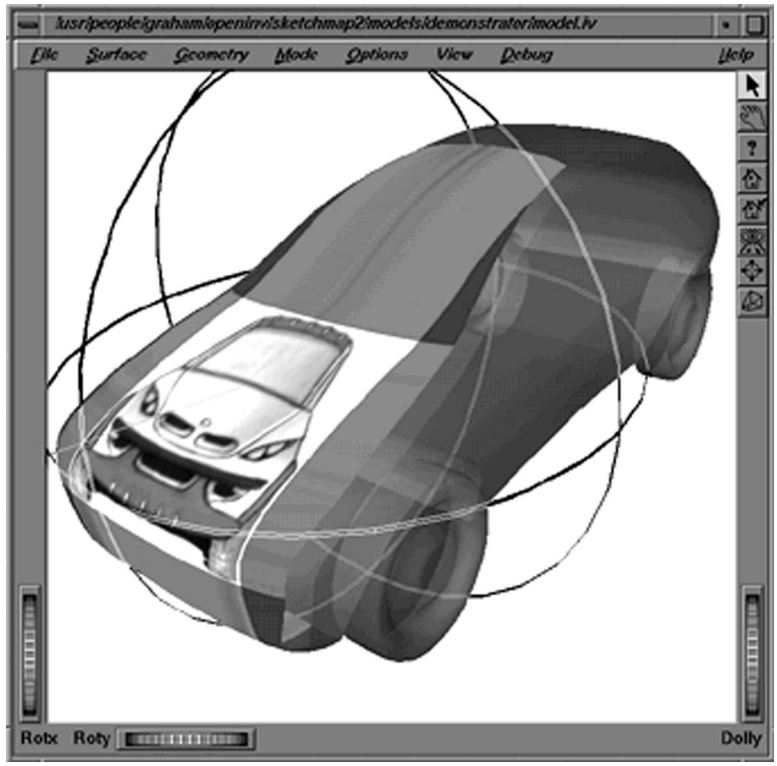

Figure 13 Front view placed onto the surface

process. It retains the use of conventional sketches with their ease of use and multiple-viewing characteristics.

Sketch mapping has been used in Coventry University and elsewhere, though experience of its use is still limited. In particular the interface tools need more testing. However, it gives cause for optimism that it will have a good level of utility.

4 *Conclusions*

Direct modelling inhibits the consideration of multiple alternatives, which is generally considered essential in concept design, in the early phase of idea generation. This is a convergent approach when a divergent one is required. It also does not support the important management intervention point evaluation requirement of viewing alternative concepts. Though direct modelling is inappropriate in a divergent phase of concept modelling, working directly in CAD from initial concept sketches allows the designer to engage at an early stage with the three-dimensional characteristics of the design. It cannot replace the conventional sketch based approach, though a

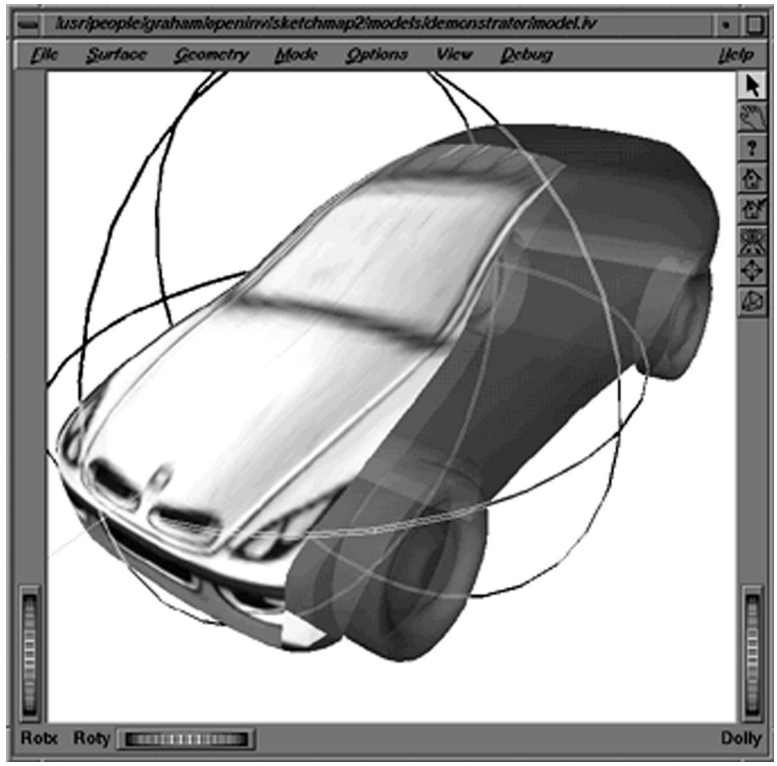

Figure 14 Front view after manipulation

combination of sketch mapping and direct modelling could be useful as an iterative tool for refining models and sketch intentions.

Sketch mapping seems to support concept design with CAD, retaining the advantages of conventional sketch-based techniques, and adding the advantage of rapidly-produced animated 3-dimensional CAD sketches. The question remains of how the base model, which carries the sketches, should be created. Although the technique we have described is acceptable, a direct modelling technique for creating base models would better integrate stylists into the process. Our conclusion is that a combination of direct modelling and sketch mapping may provide the optimum process, and we suggest the following initial design process would be worth trying.

- Produce 50 or so concept sketches, and choose a ‘short list’.
- Produce and present model forms based on the chosen sketches.
- Sketch map the models with their generating sketches.
- Review the models.
- Further develop the sketches, and select the best.
- Sketch map the models with these sketches.

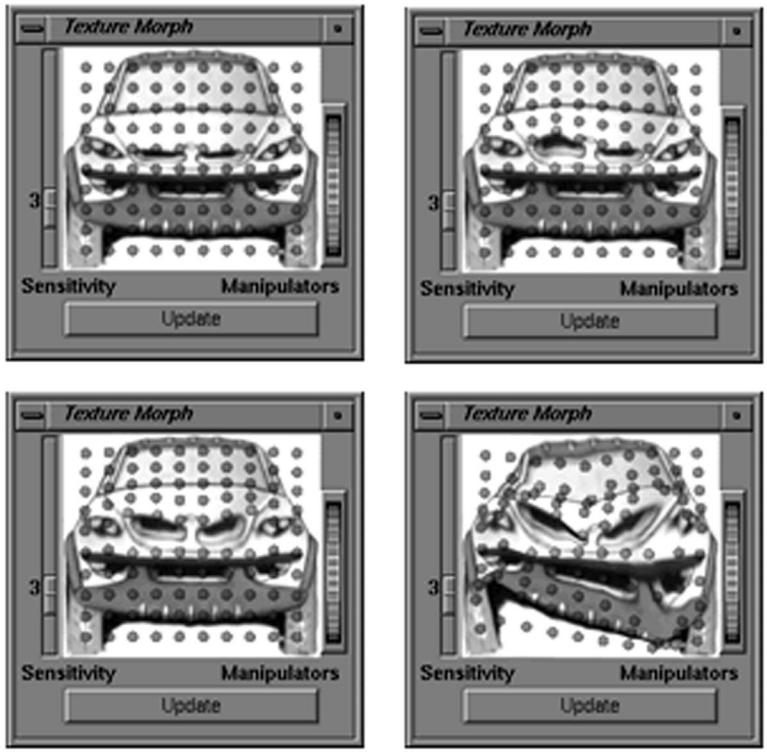

Figure 15 The morphing tool in use

- Review the models.
- Refine the models.
- Repeat as necessary.
- Continue design development in the usual way.

Acknowledgements

The three students who were our case studies: Cern Jo Chan, Richard Addleton and Mark Phillips; and the companies for whom they worked: Rover and Jaguar.