A New Aesthetic Design Workflow - Results from the European Project FIORES

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Styling design is becoming a crucial mark for the success of consumer goods on the global market. Computer Aided Styling (CAS) and Computer Aided Aesthetic Design (CAAD), but also manual work on physical models are the methods for creating optimal aesthetic shapes. The Brite-EuRam project FIORES covering 12 partners including automotive companies, styling companies, system suppliers, and research institutes is developing methods for optimizing the styling workflow. The goal is to formalize evaluation criteria for aesthetic surfaces which can then be used directly for modifying free-form surfaces in the sense of target driven design or Engineering in Reverse (EiR). The styling processes in different companies are analyzed, the concept of Engineering in Reverse is introduced, the midterm results of the project are presented. This work is the joint result of the project consortium.

Introduction

After having carefully considered the factors efficiency, quality, price, and outer appearance, the customer decides for or against a product. Market fields like the automotive branch or the consumer goods industry with a crucial emotional connection between customer and product therefore put a high emphasis on an appealing and aesthetic exterior of the product. Styling is often the final differentiation criterion among products competing on the market, since their functionality and quality have more and more adjusted to one other - also at an international level - and are thus taken for granted by the customer. The extraordinary position of styling is of special importance to European manufacturers, because they

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can hardly compete against countries with a lower wage level if competition only aims at a reduced price. Moreover, European stylists are traditionally widely esteemed worldwide.

Hence, 12 European car manufacturers, styling studios, software suppliers, and research institutes have joined forces in the project FIORES *(**F**ormalization and **I**ntegration of an **O**ptimized **R**everse **E**ngineering **S**tyling Workflow)* to optimize processes of CAD use in the field of styling and design. FIORES is supported by the Brite-EuRam programme of the European Commission (BE96-3579).

FIORES deals with the optimization of computer aided tools, methods and processes in the field of aesthetic design, i. e. the development of aesthetic shapes from vacuum cleaner to car body. The target group consists of stylists and designers who work together within more or less complex process chains to create the CAD model of a product. While preserving its character intended by the stylist *(design intent)*, this model must achieve the high surface quality requested by the succeeding departments and process steps. The often company-covering process chains ask for an extremely reliable communication between all involved persons and CAD systems, a communication which can, however, be aggravated due to process-specific and CA-related problems.

In the following, the strategic environment of the styling area will first be considered and critical processes in the car body styling will be revealed. Then, a description of the basic concepts of the project FIORES, the target-driven design, and the desired improvements in the styling process will follow. After an explanation of the implementation of the concepts within the project, some mid-term results will be presented.

Critical aspects in the Aesthetic Design process

The processes of *aesthetic design* differ from company to company. Depending on the styling job, the given financial situation and time, the equipment with tools and systems, the number, experience, and last but not least the preferences of involved specialists, there can be more or less complex process chains with supporting tools from pencil to a virtual reality high-performance workstation. Nevertheless, a certain generalized global workflow can be drawn, in which most of the individual steps and tools can be integrated (figure 1). On the basis of package data, sketches are prepared, either on paper or with the help of drawing programs. After this phase of searching for ideas, stylists proceed to the modeling of 3D models which are then supposed to actualize the ideas of the drawings in concrete terms. This can be done either on a physical model, in CAS or also by using both methods. There is still a large free space for the shape definition, a free space only limited by package data and the results of the calculation departments (e.g. using FEM).

The transition to the detailing of the CAS surfaces is more or less indistinct or can be omitted entirely. This phase is characterized by an interplay of working in CAS and on the physical model (which is to be increasingly replaced by digital techniques). It starts with the creation of surfaces on the basis of the physical model or rough CAS data and then enters an optimization loop of CAS modeling, visualizing, milling, manual modeling and surface reconstruction.

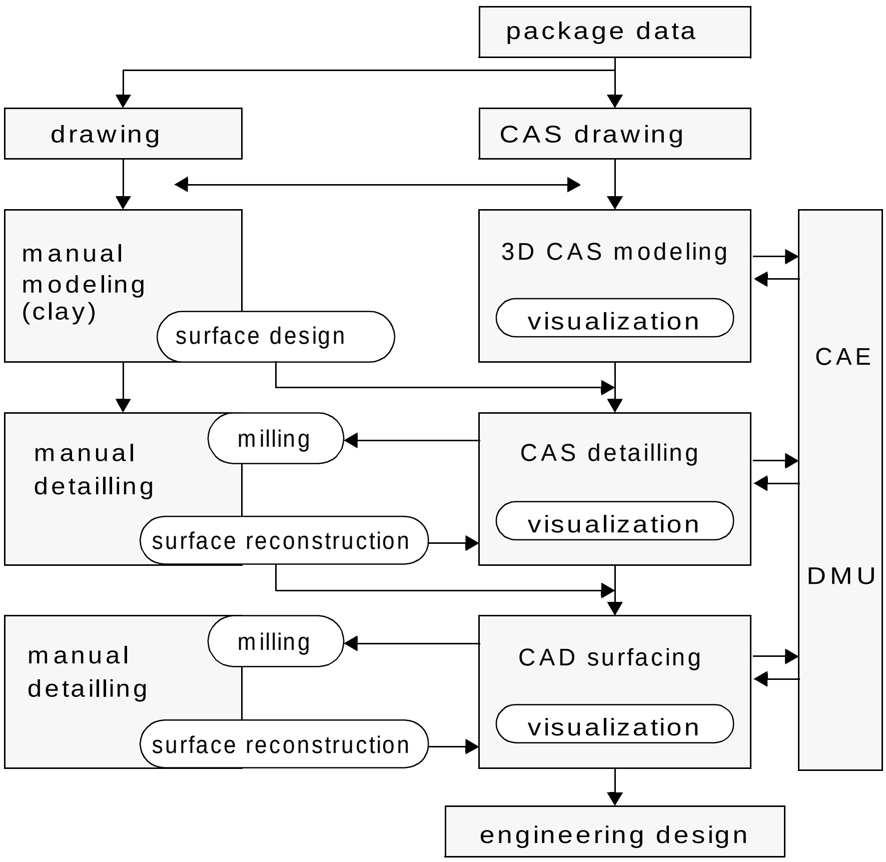

Fig. 1 : Generalized aesthetic design workflow

If the stylists are content with their model (usually the physical one), it will not be altered anymore after the *styling freeze* and is then passed on to the CAD designers. It is their job to create high-quality CAD surfaces for the following development and production processes. In this phase the need for an optimization loop may arise just as it might during the CAS detailing.

No company with a styling department will completely implement the entire workflow presented here. There are practically three principle alternatives of implementation:

- *Manual shape definition and optimization*
- *CAS/CAD with surface reconstruction*
- *CAS/CAD with a virtual model without surface reconstruction*

What are the advantages and disadvantages of these processes:

(A) Manual shape definition and optimization

Traditional working materials are clay and hardened foam. There is a direct sensory connection between stylist and model. Hand and eye perceive realistic facts. Many stylists would rather work manually only. Difficulties start when holding a physical model in hand does not suffice anymore but reliable data concerning the shape are necessary to make the model reproducible.

For simple parts, this can be done by traditional measuring and afterwards recreation within the CAD system. With more complex free-form parts like a car body, the model is usually scanned with the help of very exact measuring methods (such as laser triangulation and stereo photogrammetry), and it is then processed with a special software for semi-automatic surface reconstruction so that acceptable CAD surfaces are available in the end [HoDa96].

(B) CAS/CAD with surface reconstruction

Manual shape definition is constantly receding because physical models are expensive, and, from the processing aspect, an early use of CAD has the advantage of allowing for a higher number of themes to be tested both aesthetically and technically. In addition, CAD data can be reused more easily than models. The use of computer aided methods in the styling process is generally endorsed - in fact as early as possible, even if stylists often have to outgrow their dislike and a training and familiarization phase is unavoidable. The deep gap between manually working stylists and CAD-using designers is slowly overcome by the stylists' CAS systems which is standard equipment nowadays not only in the automotive industry. But not even in this branch is the gap closed yet. First, the quality of CAS surfaces is usually not good enough for a constructive processing and second, the object created in CAS is still always milled for final testing. If the milled model is worked at manually for the finishing touch, the CAD/ CAS data gets lost. This means that - just like in the merely manual process - the transition to CAD works via the physical model and surface reconstruction (figure 2).

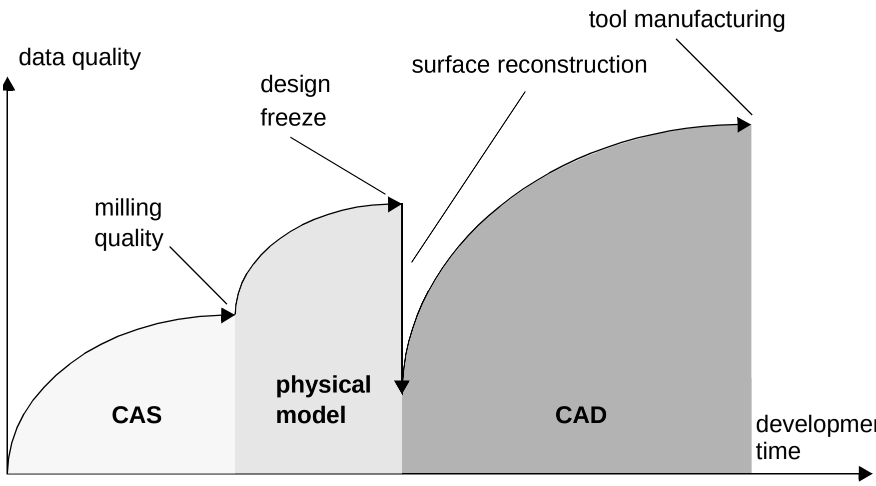

Fig. 2 : Loss of data quality when using surface reconstruction

Wherever work is done on physical models and be it only the manual modification of a small part of the milled model, surface reconstruction is unavoidable. The surfaces created through reconstruction, however, are qualitatively no design surfaces, since the scanned point clouds do not contain any information on the internal structure of the component. This is why mere automatic surface reconstruction does not work and you are continually forced to re-design with point clouds as constraints - and practically after each manual modification.

(C) CAS/CAD with virtual model without surface reconstruction

It is hence imperative to avoid surface reconstruction. The virtual model within this third process is to replace the physical one to the highest possible degree. Ideally, the CAS and CAD data are not milled anymore but visualized with the help of large 3D screen projections or virtual reality models so that the same effects can be seen on the virtual model as on the physical one. This method has its limits, however, since it is still difficult to estimate the actual proportions on a non-physical model properly. Moreover, computer-generated models can be looked at but not touched; the impression of something artificial will always remain.

There is no reason why a final evaluation should not be carried out on the milled model as long as no more modifications are made on the physical model which would depreciate the underlying data. Having once evaluated the model, it is advisable to carry out possible modifications directly in CAD only and visualize afterwards again. This avoids the hard data and quality gap of methods (A) and (B) but continues to work according to the principle of trial and error, the difference being that the milled physical model is replaced by a virtual 3D model. This model can be interactively evaluated but not modified anymore.

Thus, all presented alternatives contain gaps in process which usually come along with a loss of data quality and surface quality respectively and - above all - they need precious time. This is due to the mixture of incompatible methods (CA and manual work), models (physical model, point clouds, and different CAD surface descriptions) as well as systems (CAD and CAS). The reason is the enormous significance of the physical model for the process. Despite all efforts towards digital mock-up and virtual reality, a complete replacement of the model by computer-based techniques is not possible in aesthetic design from the present point of view and will not be in the near future. As a short-term to medium-term goal it can be aimed at reducing the number of models and concentrating on their dominant purpose which is the release of the final shape and their role as a reference model for communicating the design intent.

The alternative scenario of working with CAD methods directly on highly precise point clouds instead of mathematical surface descriptions as a data basis which is endorsed as the means to closing the quality gap, has many supporters at present on behalf of the users. In this connection it has to be critically remarked that on the one hand the required powerful CAD tools for the accurate manipulation of point clouds do not (yet) exist and on the other the problem of communicating and preserving the design intent has not been solved either.

Considering this field of problems, the FIORES project aims at simplifying the achievement of the desired shape in surface quality and aesthetic character. The ever-present trial and error loops of a groping approach are to be replaced by a straight-forward target driven design.

Target driven design

As long as a stylist works on an object manually and with simple tools, he unites all necessary abilities in one person to give a product the desired shape. He has an idea of what he wants to achieve; he knows the material to be worked at; he knows how to use his tools; and he can decide whether or not he is content with the result.

As soon as a process chain with different specialists and highly engineered tools comes into play, two problems will occur almost inevitably:

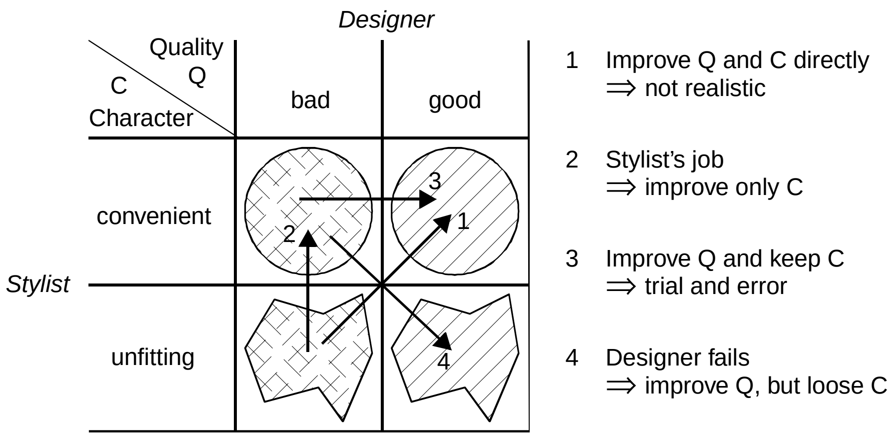

Fig. 3 : The interplay of design character and surface quality

- *Achieving quality*

  The direct connection between a stylist and his tools and material gets lost. While working on a CAD model, the user - despite shaded 3D visualization - never really knows how close he already is regarding the high-quality surface aimed at.

- *Retaining the design intent*

  When working results are passed on from one person to the other, e. g. from stylist to CAD designer, the designer never knows at what point after having achieved his own goal (high-quality surfaces) he has also reached that of the stylist (harmonic shape), because the intention of the latter can hardly be formulated (figure 3).

In order to solve this first problem, i.e. achieving a high-grade surface quality, several tools have already been developed which give the designer an idea of how good his surfaces are. Besides high-resolving object renderings, these are mainly *evaluation lines* which simulate the natural character of a 3D object [HaHa93]. This ranges from section curves to reflection lines to special curvature lines. It is not unique how these line patterns are to be interpreted, i. e. when they indicate a "good" and when a "bad" surface. The designer rather learns this from the practical work with samples, just as he will learn after a while how to create surfaces in a way that the evaluation lines deriving from them are also "good".

This is where FIORES sets in with its concept of target driven design by which the often frustrating loop consisting of surface modification and subsequent evaluation can be interrupted and reversed. The designer is rather enabled to define his goal (as for example line patterns) and then has the CAD system search for a matching surface of good quality.

There have been similar attempts, but they are all fighting ambiguity and insolubility respectively of this task. A given reflection line for example can be created by exactly one, an infinity of or not even one basic surface. It is thus the job of the system to guide the user through the application in an intelligent way without making him feel as if he could hardly influence the result. Man is the central concern, and automatism and human interaction, therefore, have to be linked flexibly within the workflow.

The second problem is by far more difficult to be solved, since the stylist´s intention has to be conveyed to other parties involved in the process and to be used as an operational control statement. In this connection, FIORES also tries to achieve results which show that designing with intentions given by styling - an *intent driven design* - is possible, for example with the help of characteristic patterns.

Both solution approaches are based on a target driven method which can be described by the term *engineering in reverse (EiR)*. Generally spoken, EiR stands for the process of generating a model according to its desired properties. As already mentioned, there is usually no unique mapping between model and properties, so that the process in the end contains an optimization loop which refines the initial model until it is as close to the wanted properties as possible.

It is highly complicated to define the criteria by which the quality of the model is evaluated and they may vary among users. Clearly put: FIORES cannot and does not want to set up standards on what is a good shape and what is not. It rather wants to formalize the criteria according to which designers and stylists evaluate the quality of their models in order to make them accessible to a (semi-) automatic EiR processing in CAD. FIORES pursues two strategies of engineering in reverse:

Direct approach

Here, those cases are considered which can be expressed in mathematical equations and then be clearly solved [And96]. In practical operation, the designer sets up a model and defines several constraints (such as continuities). An evaluation of the surface quality proves unsatisfying, since for example the shadow lines on the model show too many disturbing oscillations (figure 4). Consequently, he defines new lines which he considers better, whereupon the system from his definitions calculates and solves the equations belonging to the problem. As a result, the designer gets a surface with his defined shadow lines.

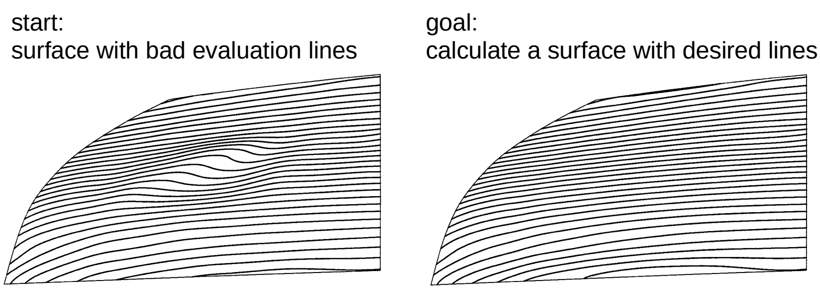

Fig. 4 : Typical application problem (car hood taken from [Nov97])

The direct approach has the advantage of exactly delivering the desired result, but it is not always applicable or the constraints it requires are too hard for industrial use.

Optimization approach

As opposed to this, the optimization approach [BDG98] with its control loop always offers a solution (figure 5), whereby this can, however, differ significantly from the desired one. According to the defined constraints, the best solution is calculated, i. e. the solution which under a certain criterion is as close as possible to the desired target. But the "best" solution does not necessarily have to be "good". The aim is to find a solution which - despite possible different appearances - is similar to the desired one, and, therefore, as good as it.

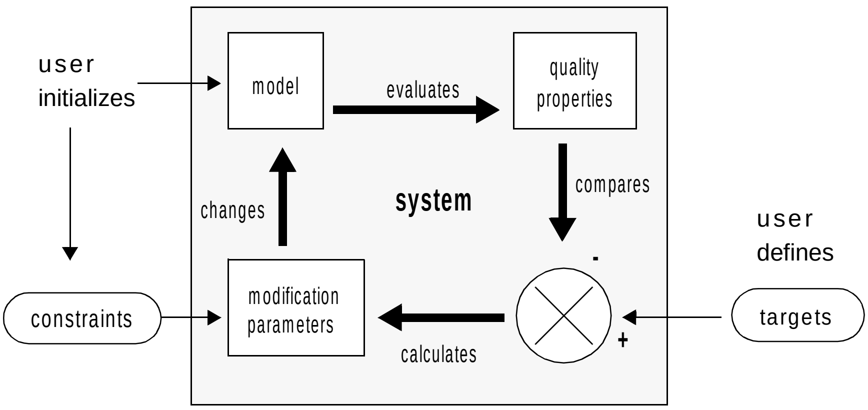

Fig. 5 : Optimization approach for EiR

Considering that much automation one must, nevertheless, have in mind that intentions of humans are to be implemented. Stylists and designers will always be best at evaluation whether a model is good or not. This is why they must always be given the chance of manual modification. In the field of aesthetic design, quality control is unthinkable without human interaction and real-time feedback.

Improving the styling process

How can a consistent use of EiR methods help at closing the gaps demonstrated in the previous chapters and to improve the processes according to efficiency and quality?

FIORES aims at minimizing the number of physical models by reducing the stylists´ inhibition concerning computer use. Introducing intuitive, easy-to-operate and expressive CAD tools would result in working with CAD/CAS from an earlier stage on than it has so far been the case, having all the positive consequences already mentioned. Thus, FIORES also supports a transition to a workflow without surface reconstruction loops. After having achieved this, the FIORES EiR tools help to reach the data quality of CAD already in CAS, so that work can be continued with CAS data in CAD at once. Moreover, the determined use of EiR methods also with product properties essential for its specific character will simplify the transition from styling to design to a large extent. There will be no more modifying surfaces until surface quality and/or shape character are achieved, but quality characteristics themselves will be predefined and changed respectively and the underlying surface will be adjusted by the system accordingly. Since EiR methods are in principle usable in other workflows with computer aided tools too, an optimization of these workflows (i.e. a better surface quality in a shorter period of time) is possible even while maintaining the method of surface reconstruction.

All goals FIORES aims at regarding the improvement of the aesthetic design workflow can be summarized as follows:

- *Introduction of computer aided tools for target driven modeling*
  ⇒ Avoiding tedious optimization loops
  ⇒ Avoiding physical models for evaluation
  ⇒ Avoiding surface reconstruction
- *Ensuring a high data quality of created CAD/CAS surfaces*
  ⇒ No quality loss between CAS and CAD
  ⇒ Avoiding physical models as reference models
- *Providing an intuitive user interface*
  ⇒ Willingness of stylists to work with computers
  ⇒ Content users

Project plan and mid-term results

The FIORES consortium was formed with the aim of connecting the fields of research, industrial application and CAD system suppliers.

The *Research Group for Computer Application in Engineering Design* at the *University of Kaiserslautern*, (Germany) acts as coordinator of the

12 partners from 6 European countries and contributes their experience in the field of CAD/CAM technology and user interfaces. Other research institutes are from Italy *IMA-CNR (Istituto per la Matematica Applicata del Consiglio Nazionale delle Ricerche, Genova)* focussing on feature-based modeling and from Spain *CIMNE (Centro Internationel de Métodos Numericos, Barcelona)* with its expertise in Computer Aided Geometric Design. *MATRA DATAVISION* residing in Paris is responsible for the CAD development within FIORES while *SAMTECH* from Liège in Belgium and the Swedish *UDK Utveckling (Göteborg)* are involved with special software for optimization tasks respectively the mathematical basics of EiR. The design and styling studio *FORMTECH (Göteborg)* which also writes specific application software marks the link to industrial users. Mere application companies within the consortium are *BMW (München, Germany)*, *PININFARINA Studi e Ricerche (Torino, Italy)* and *Saab Automobile (Trollhättan, Sweden)* for car body design and the small Spanish design studios *Eiger* and *Taurus (Barcelona)*.

It is the main idea of FIORES rather than letting the individual expert groups work independently from each other, but to ensure an early exchange of thoughts and a positive industrial feedback.

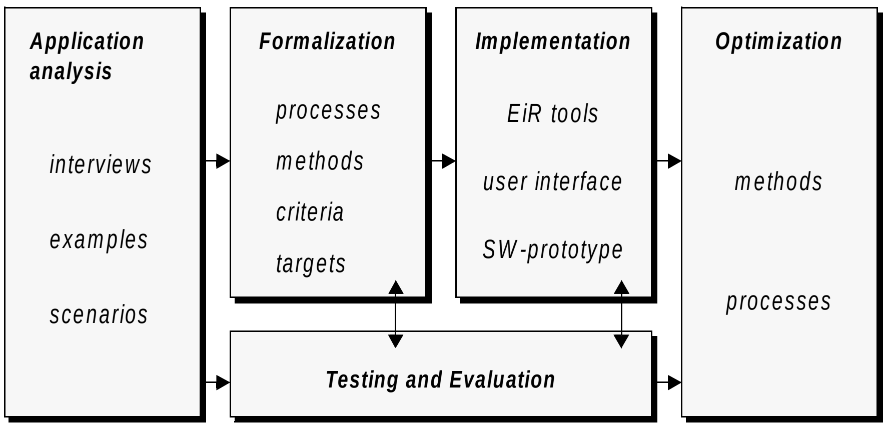

Fig. 6 : Work plan for the FIORES project

In the first project phase (*Task 1*), the participating application companies were analyzed according to differences and mutuality of their styling processes (figure 6). Therefore interviews - illustrated with examples and scenarios - were carried out with stylists and designers. Although the interviewed specialists´ fields of work as well as their tools and devices differed significantly to some degree, they, nevertheless, contained recurring similar problems.

The evaluation of the interviews gave information on the different aspects of the workflow. Of particular significance were the definable working steps of the interviewed persons, the available tools as well as their contentment and discontent respectively with them. Many problems were being discussed and wishes for improvement were uttered. A special emphasis was put on the demand for improving the user interface (*Task 3*).

Concerning the EiR tools planned by FIORES it was especially important to get information on working objectives, main product properties, and quality criteria for the evaluation of the product quality. A project-related dictionary was therefore prepared describing the characteristics in a colloquially and mathematically usable way. The different kinds of evaluation lines for example from section curves to reflection lines and character lines were included in this dictionary.

The stock-taking is followed by the formalization of results (*Task 2*). This means that processes are made explicit in a detailed way so that arising problems can be tackled systematically. Moreover, this task aimed at finding and formalizing meaningful shape structures (so called *free-form features*) which could be used during recurrent surface design jobs. A *step-like feature* was chosen to be implemented.

Task 4 with very flexible surface modification functions and generally usable optimization tools delivers the necessary algorithmic requirements for an implementation of EiR tools. The mathematical formalization of the mentioned targets, properties, and criteria done by *Task 2* however is essential for their successful use.

The software development phase within the project is terminated by a prototype which will be usable in the industrial field and will thus enable an expressive evaluation of the project results by user companies (*Tasks 6 and 7*).

Results and their evaluation

The software prototype has several functions in the course of evaluation. It should primarily substantiate the advantages of the new EiR functionality. Since its user interface will be created in close cooperation with the users, it will meet the needs of the involved specialists.

In order to present some of the FIORES results, let us pick the tool for recalculating surfaces with respect to user given shadow lines (figure 4). Task 1 came up with the high importance of shadow lines for the evaluation of high quality surfaces and the request for being able to improve the shape quality by changing shadow lines directly. As almost all involved companies had different terms for naming those evaluation lines (e.g. highlights, and reflection lines), a dictionary was implemented describing the names in technical, mathematical and application terms.

Task 2 elaborated the formal description of the shadow line modification problem and of the two approaches to solve it. In addition to this, Task 2 came up with theoretical solutions for calculating surfaces from given reflection lines, planar sections, planar sections with curvature, inflection curves, and Gauss curvature maps.

The two shadow line approaches were implemented in Task 4. Especially for the holistic approach there was the need to combine several new and already given algorithms and software packages. The forward branch of the optimization loop was actualized by an improved version of the so-called *FdF-function* developed by Matra Datavision, which is capable of very flexibly change a CAD surface of arbitrary topology. Samtech's *Boss Quattro* tool was used for driving the optimization process, while a suitable criterion for comparing the similarity of actual and targeted shadow lines had to be developed from scratch. The results of this combination are promising.

One interesting feature of the prototype user interface is the possibility of multiple real-time feedback of evaluation lines, and the *push-pull* tool (figure 7) which is designed to let the user intuitively move, push, drag, and smooth a given shadow line.

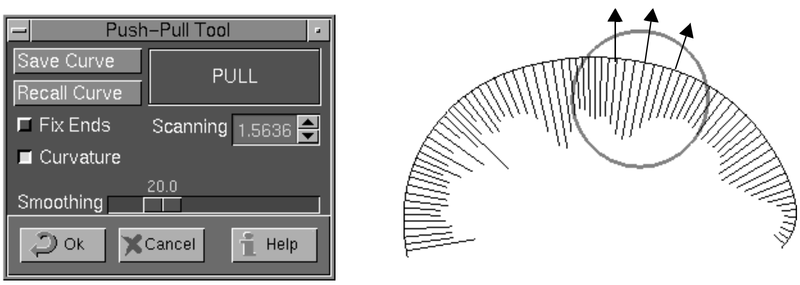

Fig. 7 : The push-pull tool for manipulating curve parts within the circle

The evaluation of the prototype in different industrial environments and applications will show that research results can easily enter into productive workflows. This goes for large companies in the automotive branch as well as for suppliers and small styling studios.

Since the object-oriented implementation of the prototype is based on an open architecture and the individual components are strictly defined, the ground is prepared for a consistent component technology parting from monolithic CAD large-scale systems. This will be advantageous for big companies concerning more flexible processes and will enable small enterprises to use affordable small tailor-made systems.

In the field of aesthetic design, FIORES will lead to a breakthrough towards object-oriented working, consistent data quality, optimization of workflow and support of component technology.

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