14

Virtual Clay Modelling*

F.-L. Krause, J. Lüddemann
Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik
Pascalstr. 8-9, 10587 Berlin, Germany
Tel.: +49(30)39006 244   Fax: +49(30)3930246
E-mail: frank-l.krause@ipk.fhg.de   joerg.lueddemann@ipk.fhg.de

Abstract

The modelling technique employed for the early phase of industrial design determines the appropriateness of computer-aided tools for the support of creative and intuitive design processes. For the transition phase from 2D sketching to the provision of an accurate CAD model, a highly interactive modelling tool is required. The challenge is to allow for both flexibility in rapid shape modification and the consistent consideration of conceptual requirements defining the engineering layout of a consumer product. The modelling technique „virtual clay modelling" is presented which is based on strong analogies to conventional methods of clay modelling. Modelling tools are provided for the industrial designer which can be guided through the virtual clay model. The virtual clay modeller is the basis for a prototype system which provides for the visualization of highlight-lines for shape evaluation, manufacturing of rapid prototyping models and VR interaction techniques to aid in the guidance of modelling tools.

Keywords

Computer-aided industrial design (CAID), conceptual requirement modelling, rapid shape definition, 3D sketching, virtual clay modelling

1 INTRODUCTION

The development area of industrial design exerts a decisive influence on the overall conception of a product. Design (aesthetics of shape) has a lasting effect on the acceptance of products by the customer and thus puts its stamp on the image of the company. The central task of design is the formal structuring of the outer surface and its integration into a long-term, fundamental design concept.

---

* This paper is based on the doctoral dissertation of Lüddemann (1996)

M. J. Pratt et al. (eds.), *Product Modeling for Computer Integrated Design and Manufacture*

In the early phase of design, the progress of the design process is documented by sketches, package drawings and tape drawings. Increasingly, computer-aided systems are being introduced to replace and complement conventional design development steps. As a result of this development, numerous media gaps appear, characterized by multiple changes between various two- and three-dimensional representational media as well as physical and computer-internal models (Krause, 1994). As a consequence, availability of computer-internal models of the design to other development areas almost always involves delay.

In addition, the transition during the early phases of industrial design from the sketching of design themes to the preparation of a CAID reference model of spline quality is not supported by computer-aided systems. The closure of this gap through provision of a sketching tool which supports conceptual design of 3D-models represents a high priority, Figure 1.

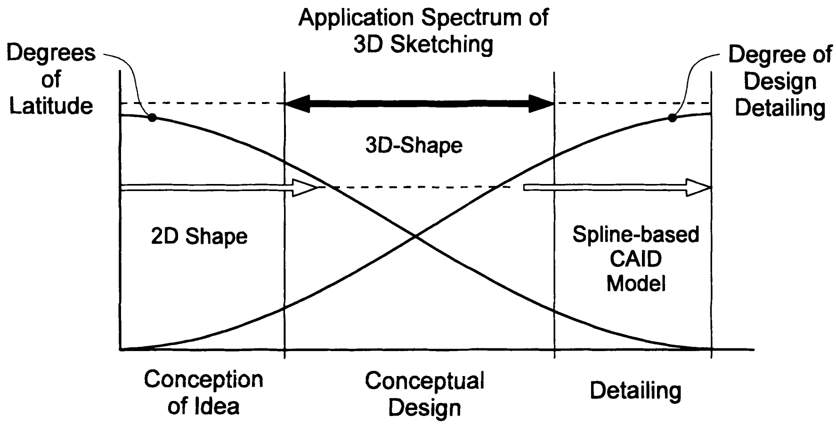

Figure 1 Application Spectrum of 3D Shape Sketching

The existence of media gaps results in reservations on the part of designers with respect to the use of computer-aided systems for the creation of form. The creative and intuitive working style during the early phase is not sufficiently supported by existing systems. The essential reason for this is to be seen in the adaptation of the abstract geometrical free-form surface modelling processes of CAD systems to the design process in such a way as not to allow for a sketch-like design activity, comp. (Tovey, 1994). The suitability of processes for design is to be judged based on the requirements of greater flexibility, a greater degree of interactivity and the transparent realization of modifications to the model based on modelling operations.

With respect to requirements, emphasis is to be placed on flexibility of modification rather than initial definition of shape. Commercial CAID systems use a B-spline basis to represent shapes. Despite the undisputed advantages of this basis, the properties of B-splines contribute negatively to the structuring of a truly interactive and effective design session, Figure 2.

Among other disadvantages is the necessity of maintaining a topology framework during the modelling process to compensate for the local character of the spline representation scheme. Proliferation of patches due to subdivision and indirect parameter influence are other examples. As a consequence, discipline in the observance of guidelines for the modelling process must be enforced by the designer himself. In a slight modification of the thesis of

Pipes (1990) one may conclude that „shape designed follows the computer-internal representation schema".

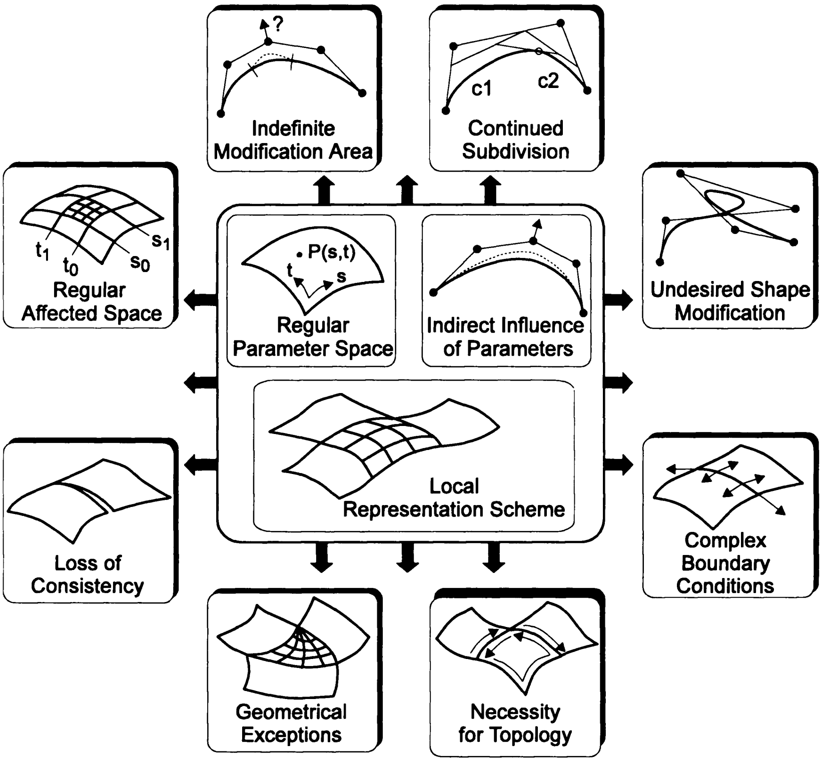

Figure 2 Selected Obstacles to Interactive Modelling

2 VIRTUAL CLAY MODELLING

2.1 Principle

In the present contribution, the definition of a sketch-like working method for design development constitutes the underlying basis for a conception of form design methods. The point of departure for this working methodology is a continuous design activity of shape modification supported in its rapid progress by a visual analysis of form and interrupted only by conceptual modifications, Figure 3. Furthermore, it is presupposed that conceptual requirements neither automatically determine forms nor compel coordination with the design. Consistent intermediate steps of the design must be attainable via inconsistent ones.

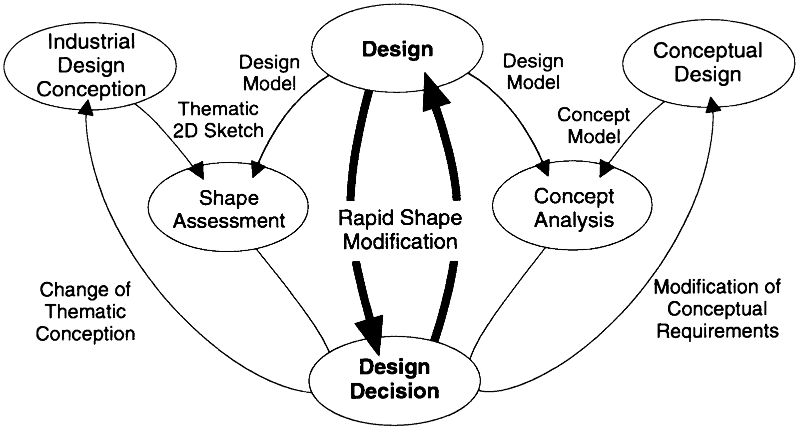

Figure 3 Methodical Order of Activities for CAID

For the realization of a sketch-like shape-structuring process in design, the present contribution introduces the virtual clay modelling approach, Figure 4. Underlying the notion of „virtual clay modelling", VCM, is the provision of modelling tools defined by rational B-splines such as to simulate their real world counterparts.

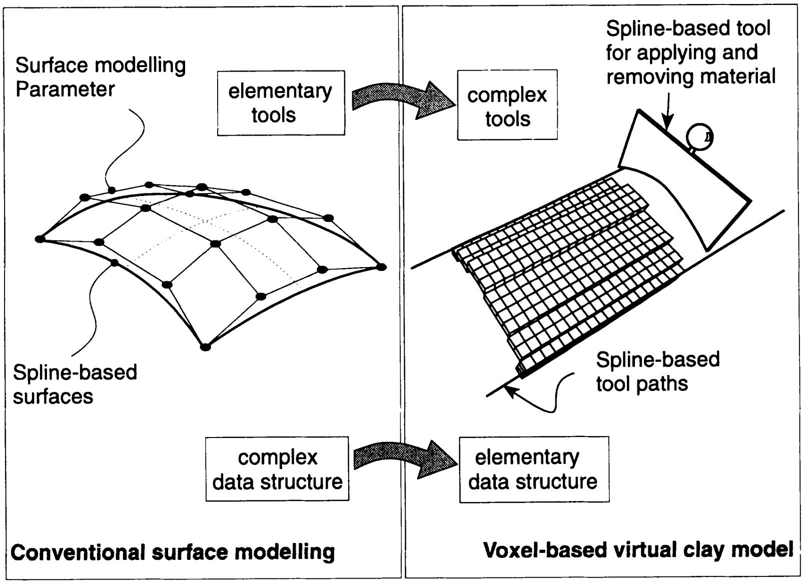

Figure 4 Principle of Virtual Clay Modelling

A modelling kernel has been developed as basis which, oriented around corresponding real models from the technology of physical model construction, provides tools such as scrapers, templates and true-sweeps for the processing of a design model, comp. Yamada (1993). Decisive here is the radical departure of the computer-internal representation scheme from conventional surface modelling:

- The design object is depicted approximately as a free-form body in a high-resolution voxel model.
- The design tools are computer-internal clay modelling tools, represented in exact fashion by spline volumes.

The change in the modelling paradigm results in the provision of complex shaped tools instead of elementary parameters for shape modification as in the spline modelling paradigm, Figure 5.

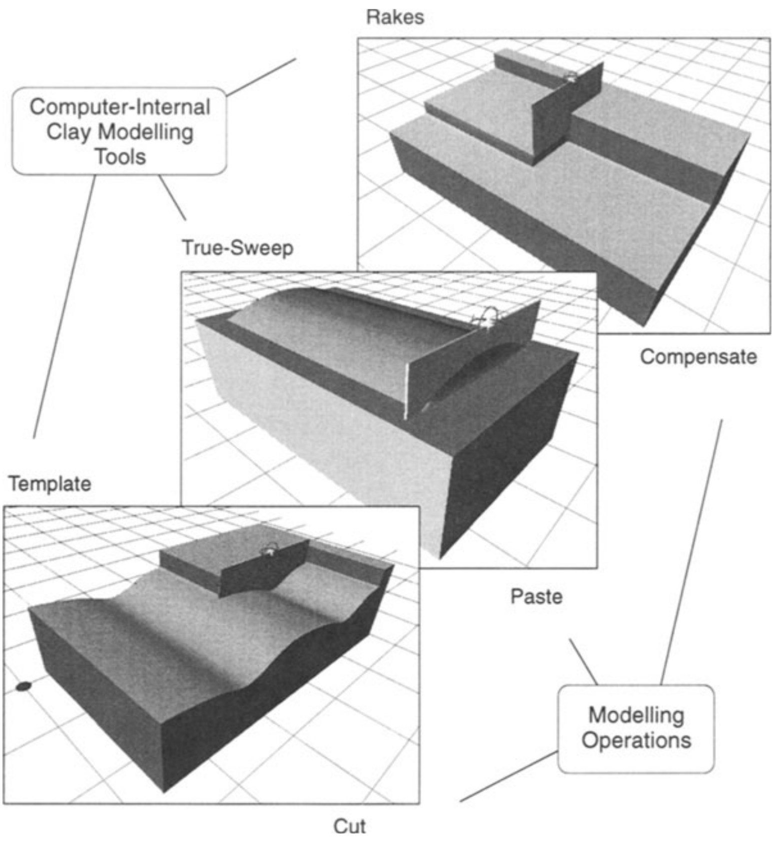

Figure 5 Basic Modelling Operations

The artifact for shaping is then represented as an ever-closed volume, an aggregation of voxels. A bounded and closed volume avoids many of the typical geometric exceptions and makes basic inquiries such as containment of a point trivial. Using the new modelling approach, computer-internal tools for model construction can be guided interactively through the virtual material with nearly real-time speed at already sufficient discretization, comp. Gaylean (1991) and Wang (1995). Analogous to the conventional process, the distinction is made between subtractive, additive and redistributive modelling operations that imprint the movement volume of the computer-internal tools into the design model.

These operations have been named „cut", „paste" and „compensate" which corresponds to the swept spline of the moved clay modelling tool. Tools of such complex form are suited to the realization of the required high-speed approximation of targeted free-form bodies and to making an essential contribution to sketch-like shape design.

2.2 Design Process

Support for the designer is provided by the distinction between inactive and active tools, since the inactive mode aids in the evaluation of the relative position of tool and shape prior to modelling. The options thus are set in an iterative manner. Modification operations can then be performed in a final operation. As a result of the iterative preparation steps, the actual modelling operations can be kept to a minimum. This approach has been used to define a relatively low-resolution mobile telephone, Figure 6.

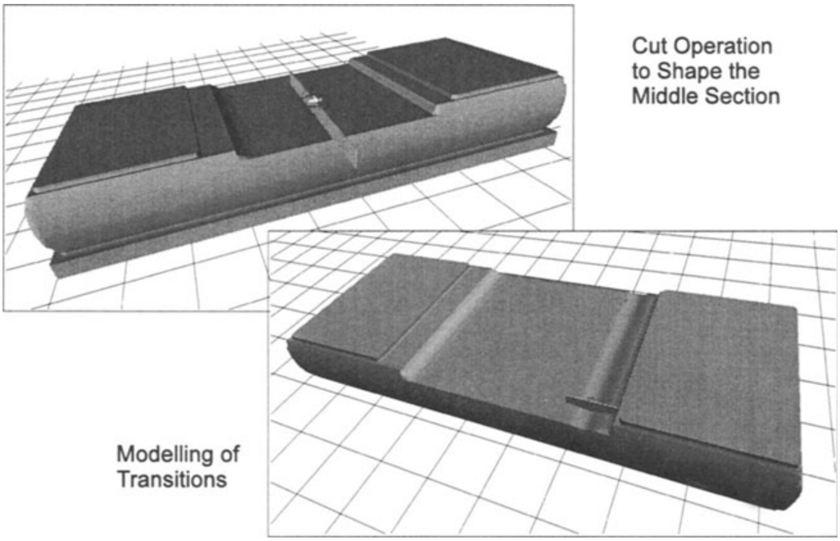

Figure 6 Intermediate Steps for Shaping a Mobile Telephone

With the virtual clay modelling approach, the user has the following options for the preparation of a modification:

- Choice of modelling operation cut, paste or compensate,
- selection of the type of computer-internal clay modelling tool and determination of its characteristic dimensions, and
- restriction of degrees of latitude of the tool movement to allow only for specific positional changes of a guided tool.

Another approach to the definition of an initial proportional model is the utilization of tape drawings in the industrial design process as generated for automobile body styling. The outline of the shape is generated by extrusion of tools defined in their profile by segments of the tape drawing.

In addition, external models can be converted to the voxel representation by applying ray-casting algorithms. Subsequently they can be modified freely to evaluate variations in the imported design. Figure 7 depicts a high-resolution sample to which minor and more significant modifications in shape have been applied. From this example it can be concluded that blended shapes can be represented by the modelling approach. Still, for the generation of blended shapes additional modelling operations have to be developed which aid the user in mooving the tools. An alternative possibility is to utilize filter which „smooth" shapes semi-automatically.

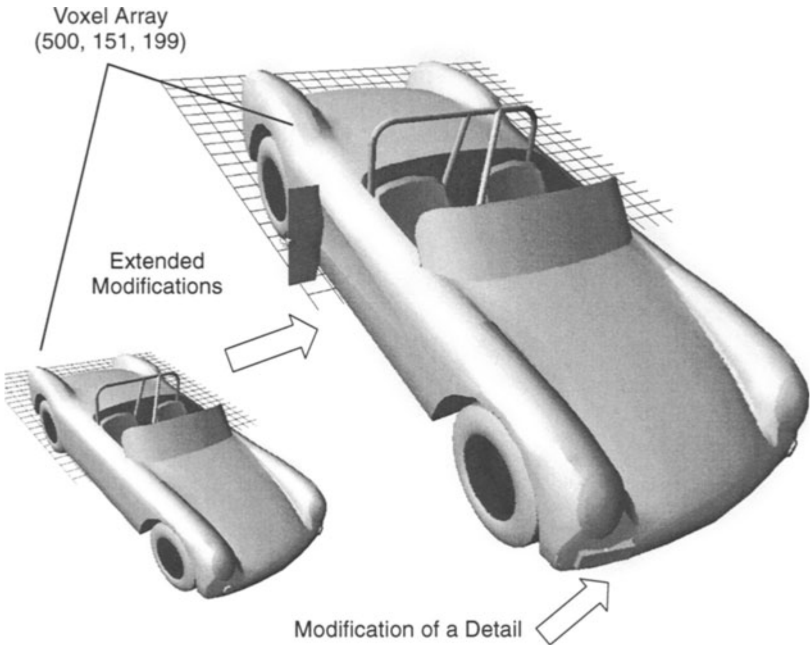

Figure 7 Modification in Details for a Highly Discretized Model, Model Data (N.N., 1995)

3 LAYOUT OF THE MODELLING KERNEL

In the development of the modelling kernel, response time of the modelling algorithms, precision of representation, degree of discretization and associated storage requirements occupied the foreground. These partially contrary configuration criteria for the modelling kernel were realized, weighing one against the other, in a compressed computer-internal voxel model that records material change along encode axes. Material codes may attribute a run length, called stic as by Jense (1989), in order to identify air, clay and also the core of the virtual clay model. The core defines the minimal hull to be surrounded by an aesthetic shape.

The data structure developed allows for rapid modelling even with highly discretized models since the modelling algorithms operate locally and in an abbreviated fashion, as used by Menon (1994) for analytical geometries. The precision of representation of complex forms was significantly increased in the discrete clay model through the imprinting of the residue of tool movements, Figure 8. At the position of voxel the residue record the extent of the resulting boundary along the main axes. In contrast to the octree data model (Meagher, 1984) the selected approach of run length encoding allows for faster updates of the data structure.

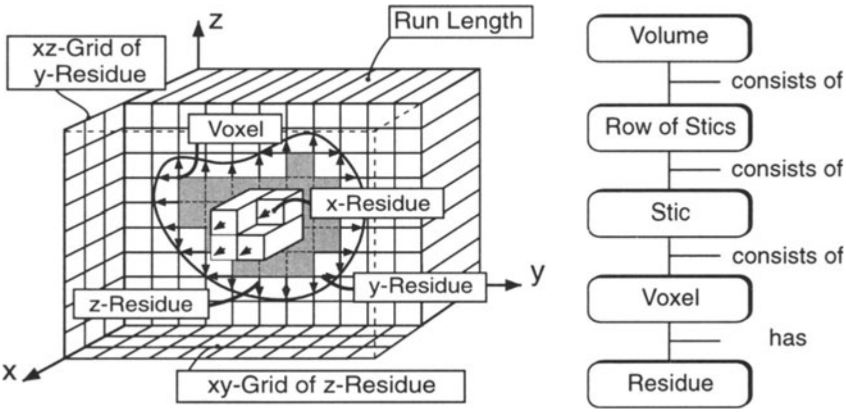

Figure 8 **Data Structure**

As an important initial point of departure in the realization of the modelling algorithms, their parallelization was conceptualized and implemented in its most crucial steps. Independently of this, the virtual clay modelling approach will profit directly from improvements in hardware performance. This is to be particularly emphasized in the comparison with conventional modelling approaches, where comparable performance improvements are not be expected due to the geometrical processes employed.

4 INTEGRATION OF CONCEPTUAL REQUIREMENTS

From the point of view of the commercial enterprise, critical factors are the continuity of product data and processes within industrial design and their coordination with the external areas of product conception and pre-development, (Mischok, 1992) and (Bertone, 1993). For the early phase of industrial design, an integrative information segment is required that provides an agreed-upon model approach for the communication of conceptual modifications without a geometrical reference being initially available, (Krause, 1995). As the design process progresses, parallel development areas must have consistent access to the conception, documented conventionally in a package, and the intermediate results of the design.

The virtual clay modelling approach includes employment of conceptual specifications for a design. Conceptual specifications define the core of the clay model, which serves as minimal hull, imposing a geometrical boundary on the desired shape. For this purpose, a modelling approach was developed that structures specifications originating in the product conception phase in a concept model using classes of technical, dimensional, ergonomic and legal specifications, (Krause, 1994). These refer to geometric instances of aggregates and components which are represented by STEP entities. To make certain of the high-level adequacy of this structural scheme, instances of concept models were created for the exemplary areas of automobile design and development of telephone devices (Krause, 1996). The concept model suitably represents a reference for the communication of conceptual modifications via cross-references to the product structure and geometry as model instances accompanying development and provides a contribution to the definition of partial models within the framework of STEP, e.g. AP214. Industrial design, mechanical design and conceptual design may refer via the concept model to common requirements on the product even if a geometric description is not yet available.

5 COMPUTER-INTERNAL CLAY MODELLING TOOLS

Conditioned by the distinction between means and object of design, the determining application parameters for the modelling process are defined in virtual clay modelling by means of the interaction techniques, the computer-internal tools employed and the processing mode. Computer-internal clay modelling tools can be represented in a parameterized fashion and further structured in formally similar variations, Figure 9.

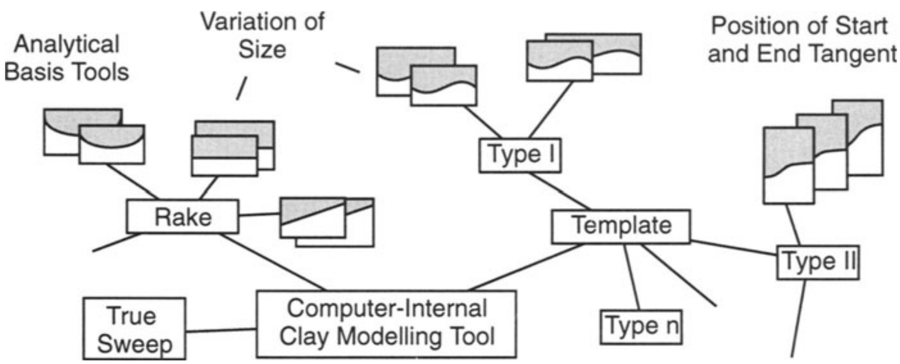

Figure 9 Classification of Clay Modelling Tools

For this purpose, an extensible class concept was implemented that makes possible a flexible assignment of interaction techniques and the integration of various input devices for a specific tool, Figure 10. The flexibility options governing transformations of the limiting and release of possible positional modifications are to be controllable by the user. It was possible to demonstrate that a multitude of forms could be instantiated in the design model using an openly selectable combination of application parameters.

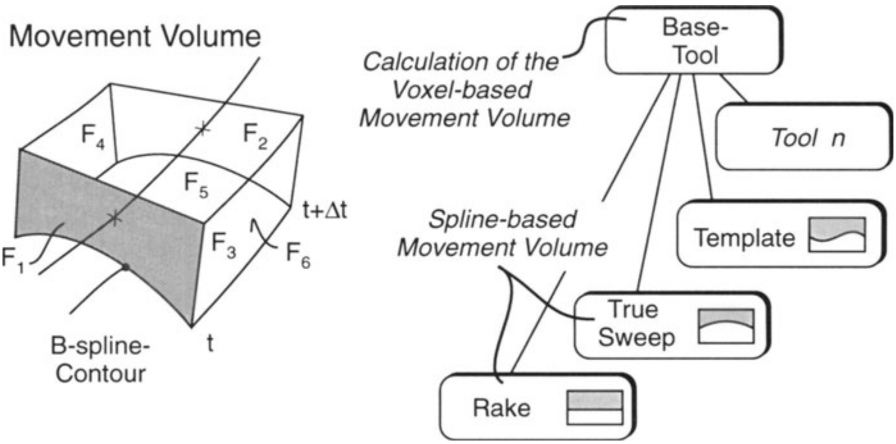

Figure 10 Structure of Computer-Internal Clay Modelling Tools

Form-dynamic tools embody the implementation of an initial approach for the representation of elastic tools modifiable by the user via parameters within a time-step of the interaction in the course of the modelling process. Above and beyond this, developmental directions have been identified in which form elements can be provided for modelling via provision of libraries of computer-internal tools. This paves the way to an alternative definition of form elements for free-form surface modelling that can be instantiated as a means of design in transparent fashion in the model.

6 EVALUATION OF FREE-FORM SHAPES

For computer-aided form analysis, the computation algorithms of highlight-lines by Beier (1994) were adapted and implemented for the discrete representation form of the voxel model in order to thus achieve independence from the graphic representation and its interpretation by the user, Figure 11.

Flexibly controllable linear light sources are suitable, as in the real-world process, for providing the ability to perform a qualitative evaluation of the sketched forms. The integrated employment of shape design and analysis methods demonstrated the applicability of the process for preparation of model modifications. The highlight-line process also served to verify the algorithms introduced in this contribution for virtual clay modelling.

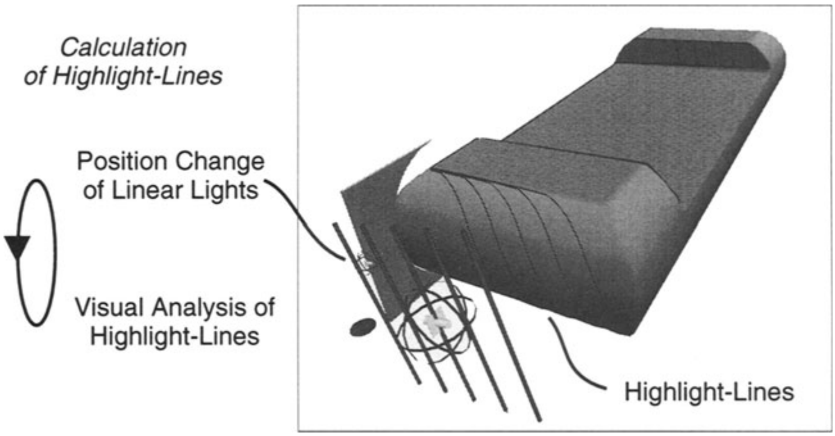

Figure 11 Evaluation of Highlight-Lines

7 THE PROTOTYPE SYSTEM VCM

On the basis of virtual clay modelling, application methods were developed for sketch-like formal structuring of a design and realized in a prototypical system, Figure 12. The potential of the modelling approach was here utilized in order to provide support for the concept evaluation, form design and form analysis phases. The prototype was developed on the basis of OSF/Motif and OpenInventor (Wernecke, 1994).

The following potentials of virtual clay modelling were investigated and implemented in examples:

- Coupling with a feature modeller for the representation of conceptual specifications as semantic data objects. The design of the concept models could in this way be performed with an integrated analysis of formulated specifications.

- The provision of data formats for rapid prototyping processes, such as stereolithography, for the production of the design model, Figure 13. It was possible to show that an abbreviated pre-processing phase during preparation of the model results from the new modelling approach. A worthwhile goal would be a direct coupling of such processes.

- The integration of virtual reality techniques into the application system as part of an investigation of the further development of interaction techniques. In a non-immersive arrangement, advantages resulted based on the targeted transparent assignment of positional changes of computer-internal tools to the resulting model modifications.

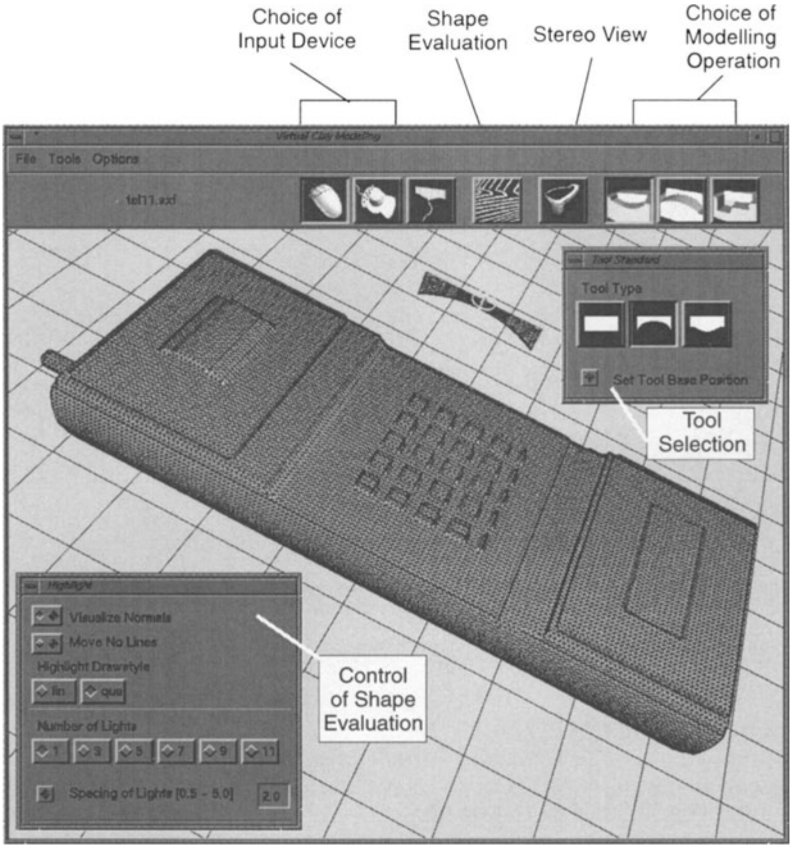

Figure 12 User Interface of VCM

Above and beyond this, significant potentials for extension of the employment of the computer-internal clay modelling tools emerge if these are made available as form elements of the free-form modelling process. The development of a methodology for design with project-, product- or even brand-specific tools paves the way for condition-dependent modelling that can be linked to industrial design-oriented requirements.

8 SUMMARY

The approach here introduced provides a contribution to promoting the interdisciplinary collaboration of industrial designers and engineers. Proceeding from user demands, methods in industrial information technology were brought together and further developed with the goal of also using IT-systems to deepen coordinated cooperation between the disciplines. For the dedicated task of sketch-like industrial design, it was necessary to shake the foundations of geometrical modelling in order to be able to close a gap in the process structure of design using the methods of virtual clay modelling. In this way, it was also possible to open up promising perspectives for further research work in this area.

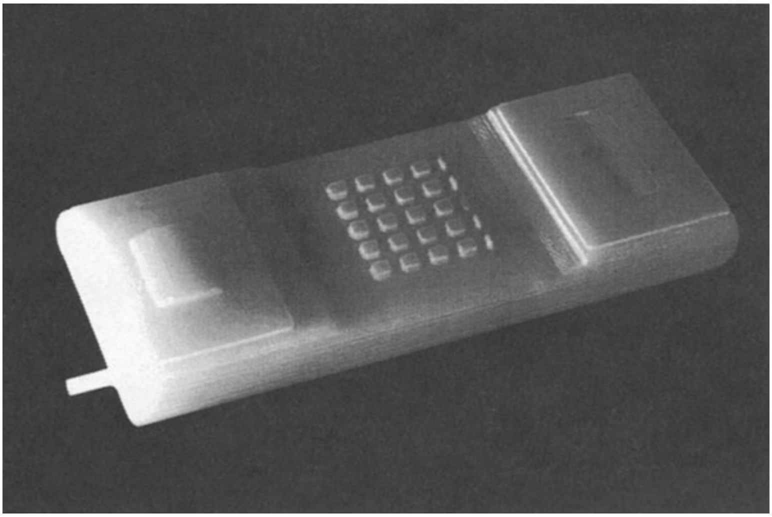

Figure 13 Photograph of the Rapid Prototyped Physical Model

9 ACKNOWLEDGEMENTS

We thank cand.-inform. Anja Kutzner, Dipl.-Inform. Askan Striepe, Dipl.-Ing. Dipl.-Des. Timm Kehler, Dipl.-Ing. Philipp Thürwächter, cand.-ing. Uwe Rothenburg and cand.-ing. Jens Neumann for their contribution to the presented work.

10 REFERENCES

Beier, K.-P. and Chen, Y. (1994) Highlight-line Algorithm for Realtime Surface-Quality Assessment. Computer-Aided Design, Vol. 26, No. 4, April 1994, 268-75

Bertone, N. (1993) No Limit Design. International Conference on Time to Market in the Automotive Industry, Torino, Italy, 15.6.-17.6, 1993, 199-206

Galyean, T.A. and Hughes, J.F. (1991) Sculpting: An Interactive Volumetric Modelling Technique. Proceedings SIGGRAPH '91, Computer Graphics, 25(4):267-74

Jense, G. J. (1989) Voxel-Based Methods for CAD. Computer-Aided Design, Vol. 21, No. 8, 528-33

Krause, F.-L.; Lüddemann, J. and Kehler, T. (1994) Rechnerintegriertes Industriedesign. VDI-Berichte Nr. 1148. VDI Verlag: Düsseldorf, 1994, 501-16

Krause, F.-L.; Lüddeman, J. and Striepe, A. (1995) Conceptual Modelling for Industrial Design. Annals of the CIRP 44/1:137-40

Krause, F.-L.; Lüddeman, J. and Rieger, E. (1996) Feature-Based Modelling of Conceptual Requirements for Styling. Proceedings IFIP WG 5.3, Life Cycle Modelling for Innovative Products and Processes, Berlin Nov./Dec. 1995, F.-L. Krause and H. Jansen (Edts.), London, Chapman & Hall, 1996

Lüddemann, J. (1996) Virtuelle Tonmodellierung zur skizzierenden Formgestaltung im Industriedesign, accepted dissertation, Berlin, 1996

Meagher, D. (1984) Geometric Modelling Using Octree Encoding. Computer Graphics and Image Processing 19, 1982, 129-47

Menon, J.; Marisa, R.J. and Zagajac, J. (1994) More Powerful Solid Modelling through Ray Representation. IEEE Computer Graphics and Applications, May 1994, 22-35

Mischok, P., Alber, S.; Robb, D.: Anwendung neuer CA-Techniken im Automobildesign der BMW AG. VDI-Berichte Nr. 993.2: VDI Verlag: Düsseldorf, 1992, S. 141-157.

N.N. (1995) The Open Inventor, Release 2.0, 1995

Pipes, A. (1990) Zeichnen für Designer: wie Produkte ihre Form finden. Augsburg: Augustus-Verlag, 1990

Tovey, M. (1994) Form Creation Techniques for Automotive CAD. Design Studies, 15(1):85-114

Wang, S.W. and Kaufman, A.E. (1995) Volume Sculpting, in: Symposium on Interactive 3D Graphics, Montery CA: ACM SIGGRAPH, 1995, 151-56

Wernecke, J. (1994) The Inventor Toolmaker - Extending Open Inventor, Release 2. Reading Massachusetts: Addison-Wesley, 1994

Yamada, Y., 1993, Clay Modelling: Techniques for Giving Three-Dimensional Form to Idea, Car Styling Extra Issue, Vol. 93 ½

11 BIOGRAPHY

Prof. Dr.-Ing. Frank-Lothar Krause, born 1942, studied Production Technology at the Technical University Berlin. In 1976, he became Senior Engineer for the CAD Group at the Institute for Machine Tools and Factory Operations (IWF) of the TU Berlin and earned his doctorate under Prof. Spur. Since 1977, he has been Director of the Design Technology Department at the Fraunhofer Institute for Production Systems and Design Technology (IPK Berlin). He earned the qualification as a university lecturer in 1979 and has been University Professor for Industrial Information Technology at the IWF of the TU Berlin since 1990.

Dr.-Ing. Jörg Lüddemann, born 1959, studied mechanical engineering at the Technical University of Aachen with a concentration on Automotive Engineering. Work on his diploma thesis was conducted at Michigan State University with scholarship funding. Since 1987, he has been Research Engineer at the IWF in the Department for Industrial Information Technology and since 1993 head of the Geometric Modelling Group at the IPK. In 1996 he obtained his PhD in the area of modelling methods for industrial design.