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TOWARDS CONTEXT-SENSITIVE MODELING TOOLS

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1. Introduction

More than 40 years from its beginnings, Computer-Aided Design (CAD) stands out as a fundamental tool in modern companies. Its strong capabilities in dealing with regular shapes makes it indispensable from designers' every day work. It is increasingly often that products require free form surfaces, for reasons that can be aesthetical, ergonomic, functional, manufacturing, assembly, recycling, or the like [Cross 2000]. These surfaces are relatively well supported by Computer-Aided Industrial Design (CAID) systems, which emerged almost ten years ago in response to an intense need for modeling free form surfaces during conceptual design phase. During this phase, designers usually prefer the flexibility of working with free form shapes to the rigidity of geometric modeling typical of CAD systems, where everything has to be defined in terms of strict geometrical parameters [van Elsas 1998].

In the design of industrial products' practice, a two-stage process consisting of styling and detailing typically takes place. Firstly, appearance and form of the product receive more attention and correspondently a CAID system is used at this stage. Secondly, details of the shape have to be established. Details are required for the verification or corrections of the characteristics that are of importance for the manufacturing processes that later have to be performed. An improper parameter or correspondence between of the manufacturing processes and the actual characteristics of the product model might significantly increase the costs and the product development time. Concerning these issues, feature-based CAD systems are better suited for these types of tasks. Because the conversion of the data from one type of system to the other does not transfer all the corresponding information regarding the geometry of the parts of the product model, in the second stage the product that has been finalized in the styling stage is recreated anew using a CAD system.

A well-known fact is that most characteristics and costs of products are defined during the conceptual design phase [Bralla 1999]. More support of this stage and improvements to its corresponding tools will hence lead to less cost, reduced time-to-market and better characteristics of products. Moreover, empirically studies conducted in academia and presented by [Sener 2002], also revealed the need of intuitive tools for the conceptual design phase. To achieve this, we have to take into considerations the practise of industrial designers and the requirements products have to satisfy. These requirements extracted from aesthetics, ergonomics, functioning, manufacturing, assembly, recycling, etc., might be into designers' consideration since the conceptual phase. As an example we may consider the case of creating the product taking into consideration both its aesthetical and manufacturing aspects at the same stage and perform refinements until it meets the expectations.

Better results from the design process can be achieved if specific tools could handle in the same stage both imprecise data required by the conceptual phase and precise data of the detail design. In either of the cases of imprecise or precise data, the users will easily alter free form surfaces and have quick

feedback of the alteration performed. An important technique used by the current CAID systems, control point editing however does not seem to be user-friendly. Moreover, it can pose seriously problems for complex shapes and much time is spent performing alteration of shapes with this tool. Instead, we should offer designers tools that recognizes features on free form surfaces and provide therefore intuitive parameters for the alteration of the surfaces based on specific shape contexts.
In this paper, we address the issues concerning so-called context-sensitive modeling tools. In the next part, we consider the shape context and describe how the designer would more effectively deal with free form shapes in the context-sensitive environment. We also present our interpretations for the support of aesthetical shape context and of shape reuse context. In the third part, we present some possible shape contexts on a case study and analyse how they can be correlated to shape constraints and/or parameters, which are the means to alter surfaces. Some attention is to shape reuse, which provide conceptual designer with tools that make possible the use of information that is not available in electronic form and would be extracted from existing models. In the fourth part, we present the research method for the development of the context-sensitive modeling tools.

2. Shape Context

During the design of industrial products, designers perform multiple switches between different contexts, and they cannot cope with few contexts involved by the design process at the same time [Cross 2000]. The context-sensitive modeling tools that represent the collection of shape contexts would provide them with tools specific to one context and better capture the design intent. Each shape context is a reflection of a context on the shape model. A shape context is materialized by specific parameters, but also by constraints that the shape has to satisfy regarding its context. We therefore mention about a shape context when a collection of constraints and/or parameters is available to the user. One parameter or constraint in action regards as a shape context. A shape context represents therefore a collection of shape constraints and/or parameters that allow the designers via procedures to alter shapes with the aim to satisfy specific requirement(s). As mentioned before, these requirements can be aesthetical, ergonomically, functional, manufacturing, assembly or the like.
The result a procedure produces on a shape through a shape context refers to as a shape image, as detailed by [Vergeest 2001b]. The collection of all shape images though all shape contexts assures that the product satisfy the requirements. The context-sensitive modeling tools would assist the designer with manipulation handles specific to different shape contexts. Within a shape context appropriate parameters and/or constraints intuitive to the designer have to be established. Hence, the ultimate aim is to map each shape context to intuitive shape parameters and/or constrains.
Shape contexts are already presented in the literature in different forms. Conceptual, detailing, manufacturing or assembly views are implemented into the WebSPIFF feature-based modeling system introduced by [Bronsvoort 2001]. These views can be regarded to as specific shape contexts. Conceptual and assembly views can deal with the whole model, whereas detailing and manufacturing deal with parts of the product model. The system manages for the validity of applications from different views through constraints that ensures for the validity of the product model. One shortcoming of the system relates to the fact that no other support is presented to the user within a view. Instead, in a context-sensitive environment, whenever the user would like to perform modification to a surface in respect to a specific context, then he/she can choose between those parameters/constraints of the shape context. The modeling task would be greatly facilitated when free form surfaces will present intuitive manipulation handles to the designer.

2.1 Aesthetical Shape Context

Aesthetical appreciation of products is based on the evaluation of parts or of complete products [Tovey 2000]. However, this process requires individuals' opinion and a generalized decision over the influencing aspects and their level in the aesthetical appreciation is still open for debates. Most of times, this decision is left to the designer or designers' team [Tovey 2000], who after an initial creation of the model will perform local changes until the agreement over aesthetical appreciation is met. However, systems supporting aesthetical shape context are presented in the literature. The Computer-Aided Styling (CAS) system introduced by [Fontana 1999] allows large control over the shape and real-time visualisation of the modifications performed. The user selects the influence area to be affected by the modification and control parameters, like evaluation, reflection, or section lines, can be modified within this area. Moreover, different continuity conditions (like G^{-1}, G^0, G^1, G^2) can be specified on different portions of the boundary. The local shape deformations performed this way are related to free form detail surfaces that are on a primary surface. They are regarded as free form features by displacement or by elimination. Example includes step-up or -down, cavity, bump, hole, etc. Although, the system allows large control over the modifications performed on surfaces, it fails when the creation of a new primary surface is required. Hence, the possibility to make reuse of a surface from an existing product as it will be detailed later in the case of shape reuse context has no support.

In the area of local modification of free form surfaces, most commercially available systems are based on control points editing, tangent vector modification, etc. However, for a conceptual designer these tools are not intuitive and they do not represent the correspondence between what designers use in the physical clay modeling and what they have to use virtual modeling for the same task. He/she would prefer intuitive parameters that have fast feedback to the alteration of shapes.

For the aesthetical shape context, a number of tools are relevant. One of them refers to the continuity conditions of the surfaces. Others can refer to curvature, symmetry or ratios. Initially, the designer might not be aware of these tools. However, the option for a specific tool belongs to him/her and an increased efficiency can be expected when providing him/her with these tools.

2.2 Shape Reuse Context

Nowadays, in the design practice, increased number of designs starts from a previous design and not completely from the beginning. Besides of the decreased in the new product development time, in this way also the quality is improved. Empirically studies conducted by [Duffy 1999] confirmed that *Design by Reuse* is among the efficient strategies used for shortening the products development time. This might appear in the form of shape reuse, reuse of information about a precedent design, etc. We focus on shape reuse and relate it in our approach to the notion of shape reuse context. This shape context might appear in the design process as a creative act when the source of inspiration is external, *e.g.* from nature, or whenever the need to switch from physical clay modeling to virtual modeling appears. After coping a desired shape from a physical object into the virtual model, the designer is provided with appropriate constraints and/or parameters to later handle the shape.

Shape reuse can be regarded as a step of the reverse engineering process. It consists of scanning the desired shape and obtaining a parameterised shape after the fitting process. In [Vergeest 2001a], a ridge feature observed on an existing product is desired into the new model. The creation anew of this feature in the CAD system will take much time, and hence the designer prefers to directly copy it from the existing product and inserted into his/her current model (Figure 1). After scanning it, the fitting process performed minimizes the directed Hausdorff distance. In this way, the designer can make use of the exact parameters of the feature for later modifications. These modifications are required either to adequately fit the shape into the model or to alter it whenever is desired.

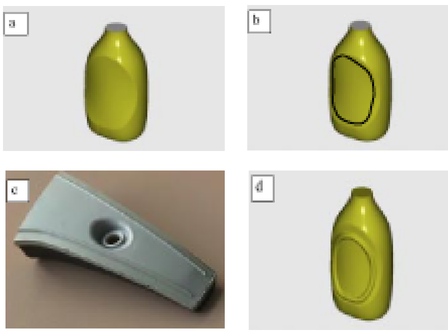

Figure 1. Estimated steps to be performed when desired shapes from existing objects have to be incorporated into CAD systems; a) Model in progress; b) Selected place where a new shape feature is desired; c) Desired shape observed on an existing object; d) Model after inserting the desired shape

Therefore, within the shape reuse context, constraints and/or parameters are made available as means for later modifications of the reused shape. This can be achieved if we recognize on the raw data point set features that hence might incorporate intuitive parameters to the designer.

3. Case study

We have performed a case study to analyse the modeling activities performed for given tasks. The case study consisted of three assignments. The first assignment required that an existing soapbox product should be reproduced within the CAID medium. The second assignment required that the model should be enlarged by 20%. Finally, in the third assignment the top of the model should be modified to fit inside another new type of soap that presents a rounded top. The existing model is presented in Figure 2. We have used Maya from Alias|Wavefront for this case study.

Figure 2. The physical plastic soapbox

For each assignment it have been observed which are the steps that require more effort for completion compared to corresponding steps from other modeling environments (e.g. physical clay modeling). These steps are considered critical as they took more time and required the maximum skills from the user. Moreover, the other way around has not been ignored. That is, we observed the steps that are better supported by a CAD tool compared to those from the other modeling environments.

Analysis of the first assignment

For the generation of the soapbox model (i.e. reproducing the physical model into the CAID medium), the modeling steps performed are briefly outlined below:

1. Create a NURBS curve primitive (rectangle);
2. Fillet the corners of the rectangle;
3. Duplicate the rectangle, move it up, and loft the two rectangles;
4. Repeat step 3 to make the closing surface on the lower part;
5. Make the two ridge surfaces, intersect them with the lower part, project the intersecting curves on the lower part, and with the new curves trim the lower part;
6. Attach the two ridges to the lower part;
7. Duplicate the lower part and constrained rotated (180°) around an axis to realize the upper part of the soapbox.
8. Trim the upper part with a plane to discard the closing part.

For the generation of the upper part of the soapbox, a different approach could be used that consist of repeating the steps 1,2,3,5,6 from the generation of the lower part. The latter approach costs however more time and effort. The generated CAD model is presented in Figure 3a.

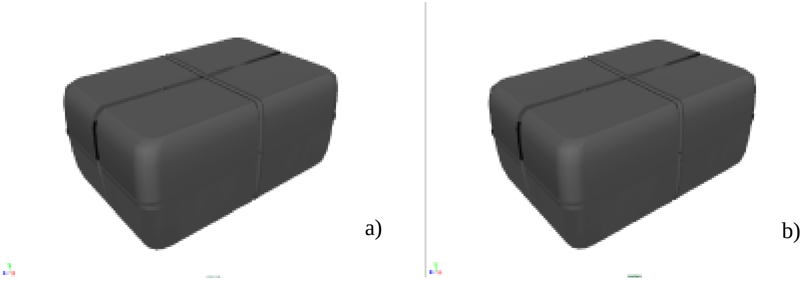

Figure 3. a) Model obtained in assignment 1; b) Enlarged model obtained in assignment 2.

Many tools have been involved for the generation of the soapbox model. We observed that constraints used referred to alteration of a shape in one direction, construction of perpendicular curves, filleting of two specific curves, constrained movement/ rotation along an axis, or extrusion of a curve along another curve that defines the profile of the extrusion. For the soapbox model, the aesthetical context a ratio parameter can be used between the length and width of the model.

Analysis of second assignment

The model generated in the first assignment appeared to be quite small for a common sized soap. Hence, a 20% enlargement had to be performed. This task can be related thus to the functioning shape context. It had been relatively easy achieved by changing the attribute's values of the scaling tool in each of the three directions. The new generated model is presented in Figure 3b. Compared to the previous model, no difference in the shape of the model has been generated when the scale tool is used. However, compared to physical clay modeling, this tool is relatively well supported within the CAID medium.

On the one hand, designers need also the possibility to input values of the scaling function in one step rather than having to divide the amount into parts equally distributed in the three directions. It often happens in practice that designers are not satisfied with the model they are generating, and for example from aesthetical point of view, they would prefer the model to be enlarged only on some parts of it. However, scaling performed on portions of the model cannot be achieved unless the parts are not attached to each other. Within a more acceptable workflow of this assignment, designers would have the possibility to model in the functioning context were the scaling tool would provide uniform scaling operations in one or multiple directions. In addition, in the aesthetical context the non-uniform scaling operations in one or multiple directions could be provided to the designers.

Analysis of the third assignment

The third assignment dealt also with another function of the soapbox model, namely it has to accommodate a new top-rounded type of soap. Therefore, this task involved the modification of the top of the upper part of the model to present a rounded profile. It had presented no serious difficulties and had been achieved by changing the location of some corresponding NURBS control points (Figure 4a).

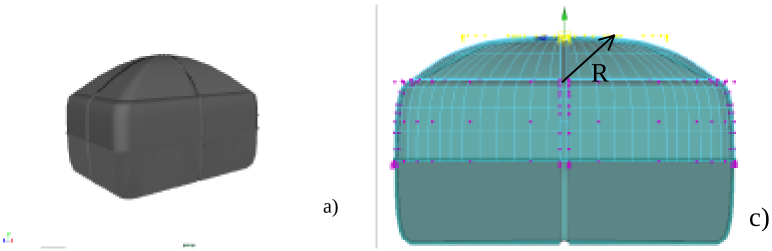

Figure 4. a) A modification step to change the top of the soapbox model; c) An intuitive parameter in place for the control point tool editing

In place of the control point editing tool designers would prefer to have familiar parameters that can be altered from a slide-bar. A modeling tool that gives designers the possibility of altering surfaces to present a displacement feature is proposed by [van Elsas 1998]. After the displacement has been located, based on its slope, rounding, height or width it still later can be modified. However, in the case of the soapbox, constraints consisted of the movement of the control points along a particular direction have somehow reduced the modeling time and made the task easier to complete.

The functional requirement correlated to a functional context and provided to the user would make the modeling process more intuitive. An example is presented in Figure 4c. In addition, the possibility defining a profile curve and later the selected surface interpolating this profile curve would give more freedom to the designers if provided in the functional context of the context-sensitive environment.

4. Conclusion and further work

For simple models, the control point-editing tool raises few difficulties to the designers. However, in the case of very complex models, this tool can be very cumbersome when used. Therefore, we have started the development of new tools for easy manipulation of free-form surfaces. These tools will operate within a context-sensitive environment based on intuitive constraints and/or parameters to the designers. Within a shape context designers will be provided with only with those parameters and/or constraints corresponding to the specific context.

Further work will include the correlation of necessary shape constraints/parameters to corresponding shape contexts. It will be based on related literature and practice of experienced designers. Design experiments will be performed both in physical clay and in CAID and further analysed. In this paper, we have presented a case study of a CAID modeling process. In a companion project carried out by [Wiegers 2002], physical clay modeling experiments have been started that analyze the most used parameters and constraints that are used in this medium. The findings from physical clay modeling experiments will be compared with those from the other experiments and most appropriate parameters and constraints will be further implemented into the context-sensitive modeling tools.

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