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INTEGRATING 3D-SKETCHES INTO THE DESIGN PROCESS

H. Diehl and U. Lindemann

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1. Motivation

During the Design of a new product a lot of things have to be kept in mind simultaneously. New solutions have to be created by combining stored knowledge in a new way. A limiting factor, especially in the early phases of design, is the capacity of the short-term-memory [Atkison 1968]. Thus, the designer needs an external representation to relieve the short-term memory. As pen and paper are very intuitive to use, sketches are an ideal medium in the conceptual phase of design [Hacker 2002].
Common CAD-Systems in contrast have a lot of different functions, which the designer has to be able to handle. Beside this the use of the CAD-functions is still not very intuitive. That's why CAD-Systems are not suitable for early phases of design. The intuitiveness of sketching is also shown in the result of a survey carried out among designers [Pache 2005]. It shows that most designers use sketches as a preparation for the work with CAD-Systems as well as during the work with CAD-Systems.
Designers often put their conceptual sketches next to the computer monitor while remodelling their solution by means of CAD functions. During this process the designer frequently has to change his perspective from the monitor to the paper and vice versa. The translation of sketched objects into CAD representations and back again as well as the iterative change of media is exhausting and time consuming. To improve this process the integration of raw sketches into CAD-Systems would be helpful. One possible solution to avoid the described problems is to scan the sketches and use them as a background images in the CAD-System. Through this the designer does not have to change the direction of his view, but still he has to translate the raw, 2D sketched objects into three dimensional objects with spatial structures. In addition it is also possible to plot existing CAD-Products to enrich them with sketched ideas.
The disadvantage of this procedure is the loss of information concerning the spatial relations [Pache 2005]. The product can not be rotated or translated anymore to get a better impression of the three dimensional structure. To avoid the disadvantages described above a new tool has been developed at the institute for product development at the Technische Universiät München. The 3D-Sketching-tool makes it possible to intuitively create three dimensional sketches which then can be easily integrated into CAD-Products. In this paper a methodical procedure for the iterative use of 3D-Sketches in combination with CAD-Systems during the design process is described.

2. New Tools for geometric modelling

As mentioned above CAD-Systems are not intuitive in use and do not support the early phases efficiently. A lot of research has been done to develop new specialised modelling tools. Some of them are described below.
One of these systems is SketcherAR [Fiorention 2002]. It uses an optical tracked pen together with a tablet as input devices. The tracking system is a high end solution and therefore expensive. Different

VR output devices are supported. The system has various functions to model freeform surfaces, lines and primitives. Special about this system is that it is combined with a proprietary CAD-System. SketchAR does not support the concretization of the raw models.
A system very similar to SketchAR is described by Wesche [Wesche 2000]. It also uses a pen based input in combination with a tablet in front of a projection table. The hardware is also quite expensive.
3D-Draw [Sachs 1991] is one of the first systems that support 3D modelling functions. Here we can also find a tracked pen in combination with a tracked tablet as input devices. The system is used to draw lines into 3D-Space. The system does not use low budget hardware and is not connected to a CAD system.
SKETCH is a 2D-system supporting a 3D-Button-Mouse. Different Strokes are defined to model geometries [Zeleznik 1996]. This system allows generating rather exact models. The generation of fuzzy product-representations is not possible.
ARCADE is a system similar to SketchAR but has its focus on the intuitive modelling of exact product representations and on collaborative design.
A system that uses multimodal input is COVIRDS [Dani 1997]. This system focuses on exact modelling. It has a CAD-interface and uses high end VR-hardware.
GIDeS [Pereira 2000] is a system that has sketching-functions and functions for reconstruction of geometries out of sketches. Through a list of defined gestures certain user intentions can be retrieved. Suggestions are displayed which then can be accepted or withdrawn by the user. A pen without buttons in combination with a tablet is used as input device. GIDeS++ is based on GIDeS but has a multimodal input. It is possible to export and import STEP and IGES-Files. Objects and edge dimensions can be changed through handwriting or spoken commands. This system allows the rapid generation of volumetric bodies that are derivates of basic geometries. The used input devices are cheap but the generation of fuzzy and abstract sketches is not possible. Igarshi [Igarashi 1999] developed a system for modelling 3D-Freeform surfaces with a 2D input device. The main use of this system is the design of spherical soft toys. Most of the systems mentioned above focus on new ways to realize geometric modelling functions using different hardware. The functions known from CAD-Systems are improved in terms of intuitiveness. The integration of raw product representations into CAD system from a methodical point of view is not focussed in these projects. In this paper we want describe a methodical approach for the combined use of 3D-Skteches and CAD-Systems. We also want to explain how this approach can help the designer to reduce complexity and to improve communication.

3. The 3D-Sketcher

The 3D-Sketcher developed at the institute of product development at the Technische Universität München supports different hardware setups. Besides a high end solution using VR-equipment the 3D-Sketcher can operate with standard hardware. In the following picture depicts the high end version of our 3D-Sketcher.
A CRT-Monitor is rotated about 45° about its own axis. The picture of the monitor is projected on a semitransparent mirror. Beneath the mirror we use the mechanical tracking system "Phantom Desktop" in combination with a space mouse (not depicted) as input devices. The user looks from above on the semitransparent mirror. Thus he can see the virtual 3D world as well as the phantom desktop. After a calibration process the interaction and projection room are merged. The user has the impression as if the virtual ink is coming out of the tip of the input device. This makes the use of the sketching tool very intuitive.
The sketcher has the following functions:

- Sketch lines in 3D (Phantom-Desktop)
- Import CAD-Objects in the VRML-format
- Export CAD-Objects in the VRML-format
- Undo
- Change colour and thickness of lines
- Zoom
- Rotate and translate the scene (Space-Mouse)

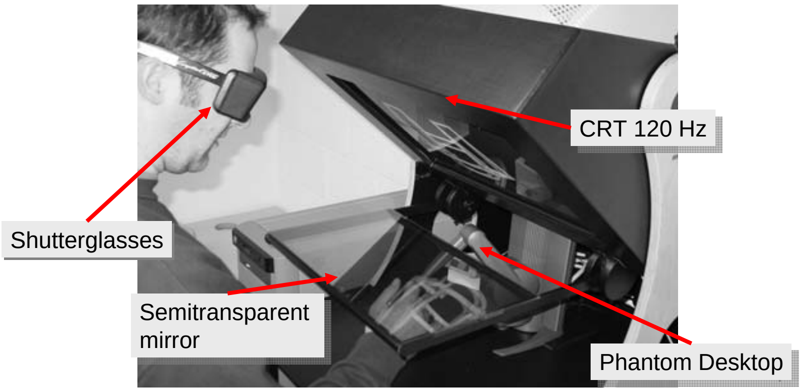

Figure 1. 3D-Sketcher

4. Use scenarios

Due to its intuitiveness the 3D-Sketcher can be useful in different situations and for different user groups like designers, industrial designers, customers and decision makers.
A designer will mainly use the 3D-Sktecher to create new principle solutions which then have to be exported to a CAD-System. There the principle solutions have to be remodelled by means of CAD-functions. Another possible application for the 3D-Sketcher is the integration of the customer into the design process. It is possible to discuss new solutions with the customer who is able to express his own ideas by sketching them into already existing solutions.
As a designer mentioned in a CAX-workshop held at the institute of product development a tool like the 3D-Sketcher can also be useful for design reviews. Supervisors often have to make quick decisions and are not always able to handle the latest CAD-Systems. With the 3D-Sketcher they would be able to make 3D-annotations in the proposed solution. These annotations are important information for the designer concerning necessary iterations. All annotations and principle solutions are managed in the same CAD-System. By means of the CAD-structure-tree the different solutions and annotations can be hidden or shown to compare them or just to reduce complexity by hiding information. In the following picture the different user groups as well as a principle solution for a part of a Stirling engine is depicted. The 3D-sketch has been imported into to a CAD-System where it is listed as a part of a product in the CAD-structure-tree.

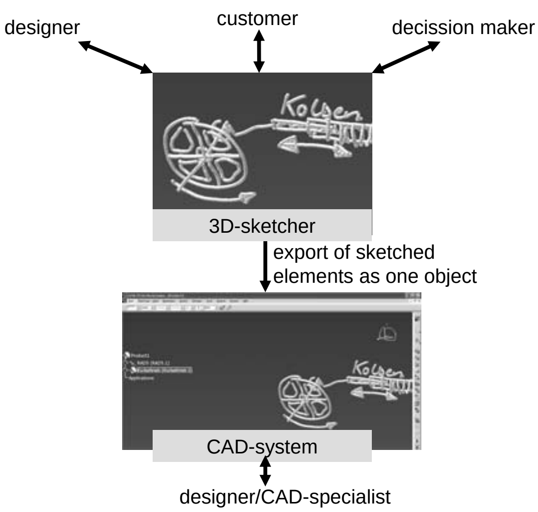

Figure 2. User groups and use scenarios

5. Structuring of 3D-Sketches

When saving a 3D-sketch and importing it into the CAD-System it is managed as one object. The sketch has no topology. This is due to the creation method of the sketch where a line exists of little cylindrical elements which are stored as child-nodes of a group node. Every time a new line is sketched a new group-node is created beneath which all cylinder-nodes of that line are placed.

A sketch can consist of different types of elements. There are geometric elements as well as annotations or symbols. These different types of elements can not be differed in the structure mentioned above, but it would be very useful to realize a topology where objects that belong to the same category are grouped beneath the same group node. Through this it would be possible to show or hide specific elements of the sketch when working in the CAD-System. For example it would be helpful to show or hide the annotations created by the supervisor during a design review.

To get the link with earlier phases of the design process, where a "product-structure" has been developed, the designer would benefit from a topology of the 3D-sketch in terms of assemblies and subassemblies. Editors for VRML or 3D-XML files have sufficient functions to structure a 3D-Sketch to create a topology where parts and subparts as well as different elements are grouped logically. One editor that can be used for such a task is Visx3D. It is possible to import a 3D-Sketch as a VRML-file.

On the right side of the screen the node structure of the loaded sketch is shown. This structure can be changed by dragging and dropping the nodes or by creating new nodes. Additionally the names of the nodes can be changed.

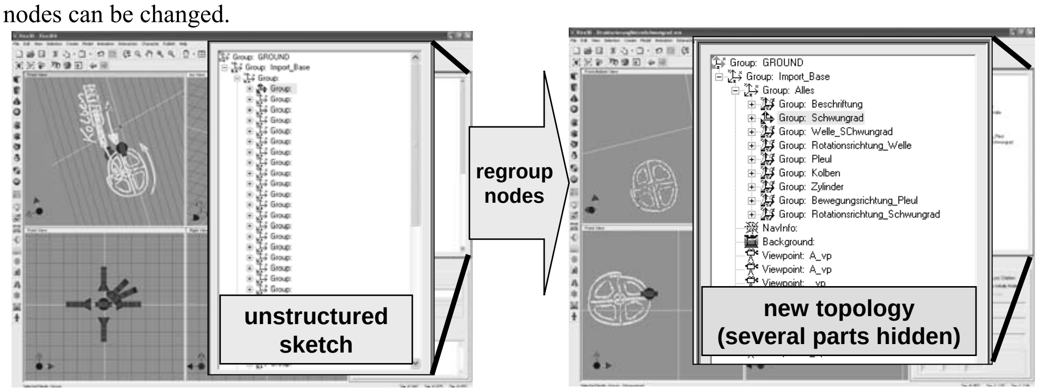

Figure 3. Structuring of a sketch

- Identify and differ the different element categories:
  - Group all annotations under one group node
  - If needed create subnodes for specific annotations
  - Name created nodes.

↓

- Create the structure of the product
  - Compare the sketch with the planned structure of the product
  - Identify the main assemblies and group all belonging lines under one node. Name those nodes.
  - Name created nodes.

↓

- Verify the generated structure by navigating through the tree

↓

- Decide which nodes have to exported

Figure 4. Guideline for the structuring of 3D-Sketches

A part of the sterling engine depicted in the subsequent picture is structured according to the mentioned functions.
As one can see the main assemblies have been created and named. In the right part of the picture only the fly wheel ("Schwungrad") is activated. That's why only the fly wheel is being depicted.
To help the designer with the structuring of the sketch a guideline is being proposed:

6. Using 3D-Sketches in combination with CAD-Systems

The great potential of the 3D-Sketcher is the integration of 3D-Sketches into CAD-Systems. So, this abstract and concrete product representations can be combined, linking the early phases of design with the more detailed design.
Günter [Günter 1998] revealed that there are designers who tend to design the whole product on an abstract level before transferring it to a more precise level and others who iterate between abstract and precise. The 3D-Sketcher in combination with the CAD-System can be used in both ways. It is possible to sketch the whole product first which then can be exported to the CAD-System to remodel it as a whole. But it is also possible to sketch certain modules or parts of the product which then can be concretized part after part . A guideline for the iterative use of CAD and 3D-Sketching can be based on the VDI-guideline 2221. This guideline differs 7 phases of design. Starting with the clarification of the task (1), the functions structures are developed (2), followed by the search for principal solutions (3). After this a structure of realizable modules is being derived (4) which then leads to the design of the decisive modules (5). The last two phases are the "design of the of the whole product" (6) and the preparation of production and operating instructions (7). The phases of the VDI-2221 are being depicted in the subsequent picture

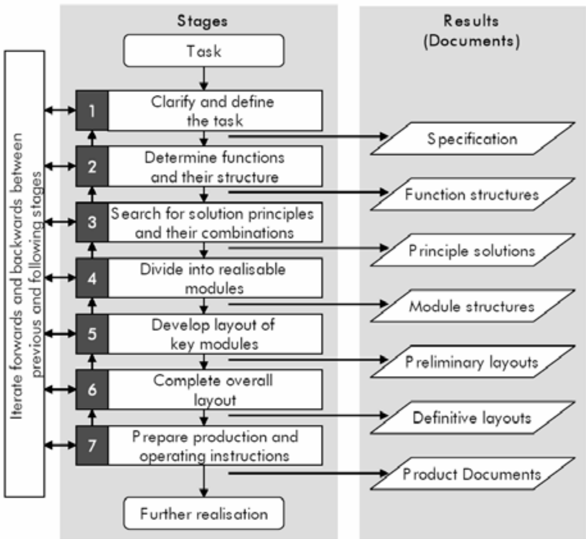

Figure 5. VDI 2221

As already mentioned the 3D-Sketcher can be used to develop new ideas which is a basic task in phase 3 "search for solution principles and their combinations". Generally the first step is a very abstract representation. This raw and fuzzy model will be detailed step by step as Pahl and Beitz [Pahl 1997] proclaim. During this concretization process the designer changes between designing the product "as a whole and working on more or less isolated details". [Hacker 1999]. Looking back at the VDI 2221 the 3D-Sketcher can serve as a link between the conceptual phase and the phase of more detailed design. Thus the 3D-Sketcher should mainly be used during the phases 3, 4 and 5. In the subsequent picture a procedure based on the VDI 2221 shows how the 3D-Sketcher should be used during these phases.

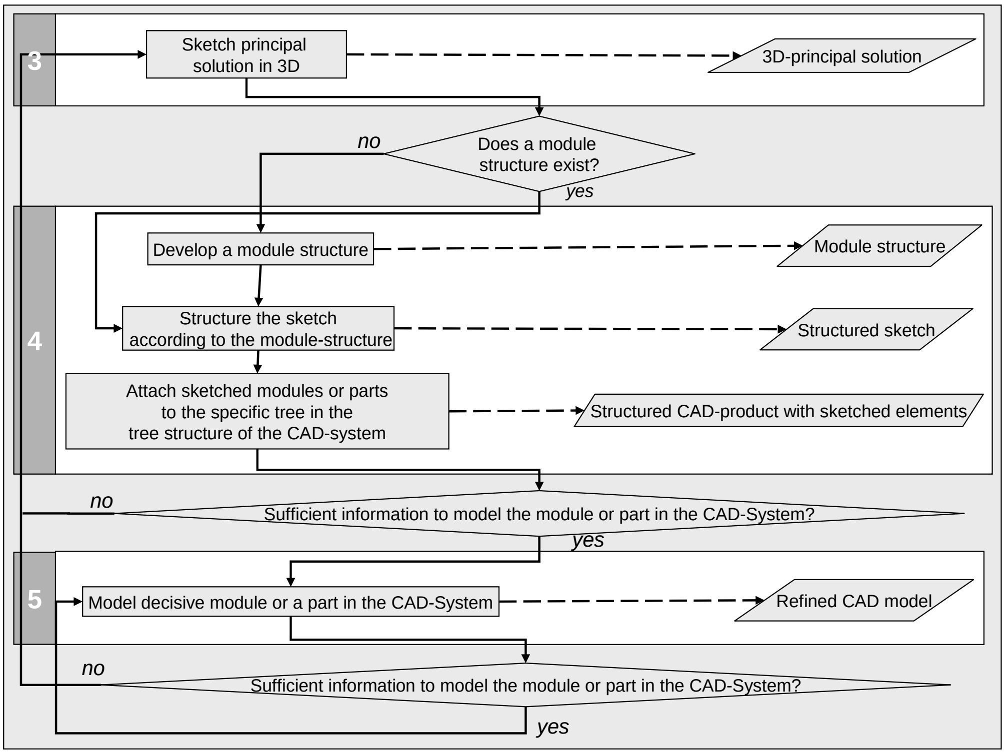

Figure 6. Guideline for the iterative use of the 3D-Sketcher during the design process

Because designers jump from abstract representation to exact CAD-models and back again as well as from the design of the whole product to the design of parts [Günther 1998], the exchange of data between CAD and the 3D-Sketcher is elementary. At each iteration the designer has to decide which modules or parts have to be exchanged between the 3D-Sketcher and the CAD-System.

Due to the formalized modelling language of CAD-Systems mistakes and weak points of the concept can be revealed [Pache 2005]. Because the complexity constantly rises during the design process and the use of the CAD-System is not very intuitive it is often necessary to jump back to a more abstract level to reduce the complexity to find solutions for the revealed problems.. By means of importing CAD-parts into the 3D-Sketcher CAD is brought into earlier phases of design.

As already mentioned at each step where product representations are being exchanged between the CAD-System and the 3D-Sketcher the designer has to decide which modules have to be transferred to the specific system to solve the specific problem. Therefore a module structure is elementary. In case such a structure does not exist the designer has to develop one.

During the structuring of a sketch a reflective process is being triggered. “Which modules are missing?”, “Which modules are too abstract to be modelled in CAD” are questions that can be assigned to this step. This reflective process also helps to avoid mistakes.

A 3D-Sketch which represents a single module should be attached to the branch in the CAD-tree which represents that specific module. In contrast a 3D-sketch which represents the product as a whole should be attached to the lowest level of the CAD-Product. After importing the sketch the designer has to decide which module has to be remodelled by means of CAD-functions. During this modelling step the designer is supported by the spatial, geometrical and functional information provided by the 3D-Sketch. If the information provided by the imported sketch is not sufficient enough to solve a certain problem it is necessary to go back to a more abstract level. Therefore the designer has to decide which CAD-objects have to be exported to the 3D-Sketcher. All parts and modules whether sketched or modeled in CAD that are not needed will not be exported

7. Outlook

Beside the exchange of sketches via the VRML-format we also started to transfer the sketches as a set of 3D-points by means of an excel macro. A big advantage of this method is the generation of an adaptable CAD-representation and the option to regroup the sketched elements directly in the CAD-System. The set of 3D-coordinates can be used to create splines or lofts. In the following picture a simple example for this transfer process is shown. In the next month we will test more functionalities of this transfer method.

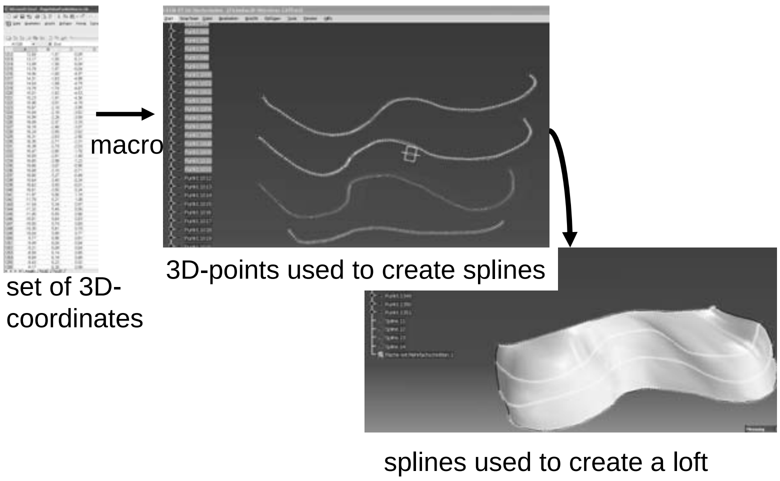

Figure 7. Import of 3D-Sketches via an excel macro

In this paper a methodical approach has been presented how raw product representations can be combined with exact CAD-models. Through this the advantages of computer aided modelling and sketching can be combined. The real use of this approach will be tested in a practical course where about 60 students have to design a new product using the CAD-System CATIA.

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Holger Diehl, Dipl.-Ing.
Research assistant
Technische Universität München (TUM), Institute of Product Development
Boltzmannstr. 15, 85748 Garching, Germany
Tel.: +49 (0) 89 289 15141
Fax.: +49 (0) 89 289 15144
Email: holger.diehl@pe.mw.tum.de
URL: http://www.pe.mw.tum.de