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COOPERATION CONCEPT FOR THE PRELIMINARY DESIGN AND MANUFACTURING STAGES

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Abstract
In this article a new approach is shown to support product modeling during the product-life-cycle stages "design" and "manufacturing". To do this we introduce the concept of design-working-spaces, apply this concept to the scope of the planning- and manufacturing-department to derive the so called planning-working-space. This concept serves for a methodological integration of the two product development stages "design" and "manufacturing" to reduce unnecessary feed-back cycles and to support both an effective information flow between them and to work on the same product at the same time.

Keywords
Parametric modeling, physically based modeling for design, preliminary design, design for manufacture, process planning for manufacture and assembly, product life cycle modeling Product Life Cycle Modeling

1 INTRODUCTION

Product development as a whole becomes an important factor for the industrialized nations. It becomes more and more difficult to meet the customers' demand and to compete on the international markets with high quality and good value products, which have to be produced faster and faster to cut down the time to market. A product passes several product-life-cycle stages during its life time. Different stages of the product-life-cycle are supported by isolated CA-systems today. It is important to ***integrate*** the ***different views among the product-life-cycle stages.*** Such an integration requires both a ***logically integrated product model*** as well as ***modeling methods*** to work with the integrated product model.

In general the development of a product begins with the product planning stage (Figure 1), where the idea of the product function arises. After it, in the design stage, the future product is modeled on

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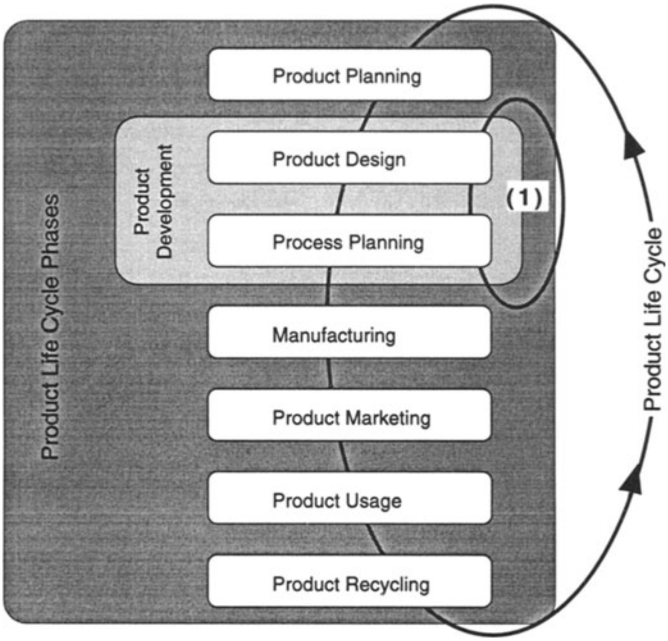

Figure 1 Product Life Cycle

different abstraction levels to become an embodiment that has to be manufactured for use. At the end of the product-life-cycle the product has to be recycled.

The product design stage or the ***design process*** covers all engineering activities beginning with modeling the product ***function***, the ***physical solution principle*** and ends up with the ***embodiment*** design of the future product (Figure 3). The ***process planning*** stage covers all activities for the realization of a product i.e. manufacturing, planning, assembly planning, inspection planning. These two stages have strong interrelationships and the better these interrelationships can be controlled the better the product will be at the end.

In this article we examine the design and process planning stage and the relationships between them. We discuss the design process with respect to the modeling layers used for designing and planning the realization of a product. We use an example to show our ideas. In Figure 2 there is seen a robot gripper which is designed for handling small parts, for durability and for low maintenance costs. A standard connection to the robot arm as well as the space in which the gripper has to fit is given by the product requirements. The working method of the gripper is as follows: The force with which the handled part is gripped is generated by a pneumatic energy source. The resulting force is then transmitted through a piston rod to a wedge splitting the force into two resulting forces which are applied to the grippers jaws. The applied pressure causes a movement of the piston rod towards the jaws and therefore the wedge causes a turning motion of the jaws which results in the gripping force of the robot gripper. The detachment of the handled product is realized by a spring (not depicted) and by reducing the pressure applied on the piston. So the spring pushes the piston back to its original position.

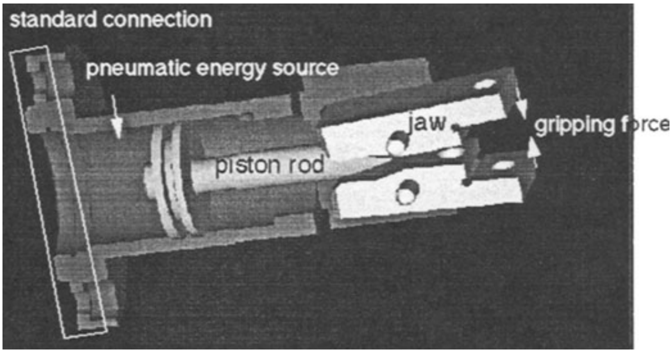

Figure 2 Product Example

2 THE MODELING LAYERS IN THE DESIGN PROCESS

In the design process the idea of a product, formalized as a product function, is embodied (Figure 3). The result of this process is a model of an artifact that is embedded in the environment by means of ***input*** and ***output*** and can be treated like a system. A ***system*** can be divided into ***sub-systems***. What belongs to a particular sub-system is determined by the ***system boundary***. Describing a proposed technical artifact by means of a system consisting of elements, which are grouped by the system boundary related with each other by input and output, we use the term ***function*** or ***product function***. If the ***input and output of the product function*** is described on the basis of ***matter, energy and information*** then we use the term ***general function***. If the inputs and outputs represent ***physical magnitudes*** like force $\vec{F}$ or torque $\vec{D}$ and the relationship between the input and output is described by a limited set of ***function verbs***, then we use the term ***special function***. The function verbs describe the proposed transformation between the input and output on a conceptual level. With reference to Roth (1994) we use the set of function verbs *Change*, *Connect*, *Channel* and *Store*. Figure 4(1) at the top of the picture shows the established function structure of the robot gripper (Figure 2). In the case of relating the input and output by a ***physical law*** that is described by a mathematical equation then we talk about an established ***physical principle***. The

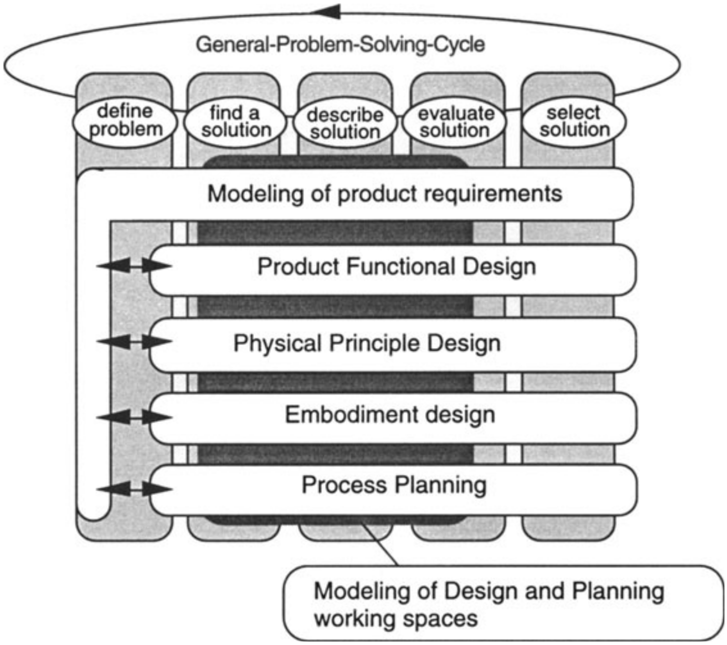

Figure 3 Modeling Layers in the Design Process

physical principle design serves for the description of the solution principle of a special function. It covers all information of the product's ***physical*** solution. This information contains the ***physical effect*** that is described by a ***mathematical equation*** and geometrical information as ***effective lines***, ***effective surfaces*** and ***effective spaces***. In Figure 4(2) there is depicted the established physical principle structure and the derived effective geometry (3) of the robot gripper. The embodiment is the most concrete one of the product modeling layers. In this layer the design process is completed by the geometrical definition of all design features, parts and assemblies.

3 DESIGN-WORKING-SPACE

A ***design-working-space*** is an ***Euclidean space*** available for the designer ***to solve*** his ***design task***. The design-working-space is defined by an envelope (geometric system boundary) and its constraints (in-/outputs). The fundamental idea comes from system theory and is therefore not limited to the geometric scope. The

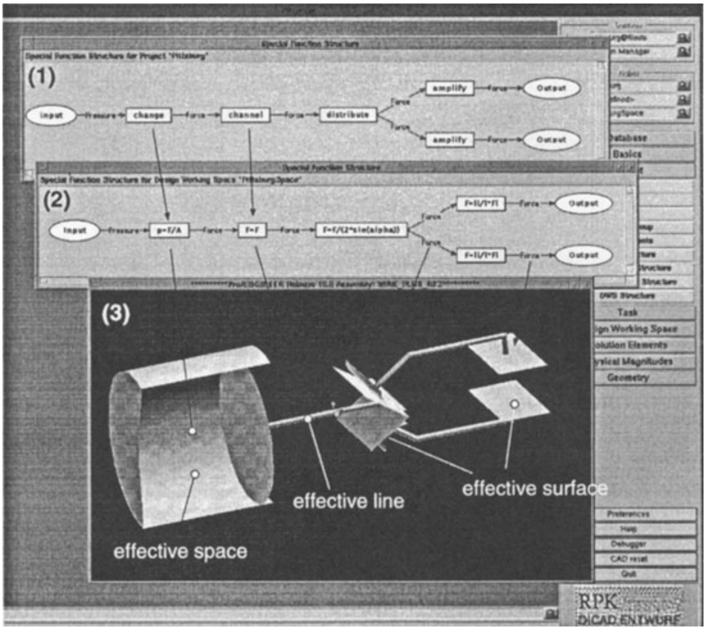

Figure 4 Modeling Structures of the Robot gripper

main purpose of ***design-working-spaces*** in this context is to ***integrate the design and the manufacturing life cycle stages.***

In Figure 5 there are three design-working-spaces which have to fulfill a special product function, like ***change force into torque*** (2) or ***amplify force by force*** (3). The system boundary of a design-working-space is defined by its maximum envelope (4), effective geometry (5) and by the physical inputs and outputs like the physical magnitudes force $\vec{F_1}$ and torque $\vec{D_1}$; the envelope and the effective geometry is represented by free form surfaces. The envelope describes the maximum space inside which a special problem has to be solved. The effective geometry is described by effective spaces and effective surfaces which transmit for example forces. The relationship between the design-working-spaces is established in this example by the general magnitude energy $E(6)$ and the special magnitudes force $\vec{F_1}$ (7) and torque $\vec{D_2}$ (8).

Design-working-spaces will be built up by the following rules:

1. A design-working-space consists of a set of elements and of a set of relationships between the elements.

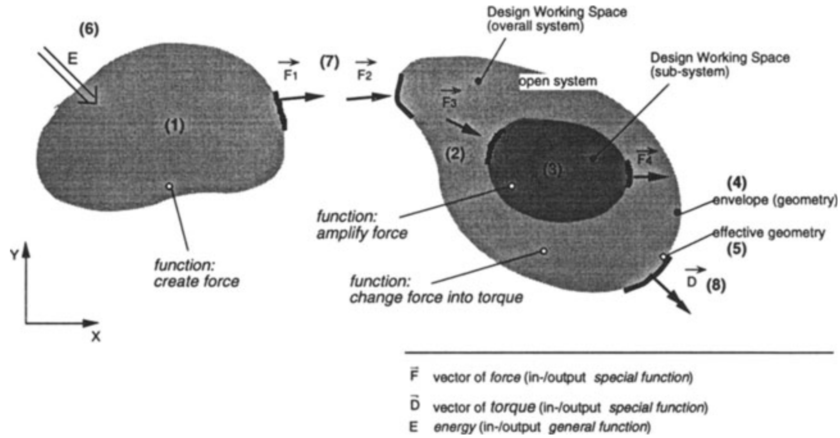

Figure 5 Concept of the Design Working Space

2. Elements of a design-working-space is information of the design stages, like product requirements, functions or physical principles. Relationships between the elements are general or special magnitudes like energy, information, matter or force, torque etc.
3. Every design-working-space can be subdivided into independent sub-spaces. If elements of different sub-spaces will be grouped together then this sub-spaces are called overlapping design-working-spaces.
4. Every design-working-space and every sub-space is defined by a system boundary. The system boundary is specified by its envelope, making available the maximum of geometric space for designing, and its effective geometry. The effective geometry defines the point at which the physical event (phenomenon) takes place.
5. A system boundary of a design-working-space has one or more in-/outputs. If a design-working-space has no in-/outputs then we talk about a closed design-working-space, on the other hand about an open design-working-space.

4 PLANNING-WORKING-SPACES

A ***planning-working-space*** is an ***Euclidean space*** available for the planner ***to solve his planning tasks.*** Planning tasks cover all tasks to manufacture a product under considerations of production costs, production times and quality of a product. The ***main purpose*** of ***planning-working-spaces*** in this context is to integrate the design and the manufacturing life cycle stages. This is done by exchanging ***not fully specified***

geometric models in the earliest design stage as possible, here in the stage of the ***physical modeling layer*** where the effective geometry is established.

The ***planning-working-space*** is defined by an envelope (geometric system boundary) and a set of constraints.

In the ***scope of design*** important ***constraints*** are

- the shape of a given effective geometry,
- the ***micro-geometry*** and the ***material*** of an effective surface.

and in the ***scope of planning***

- a given machine space,
- tool and clamping (fixture) spaces and
- kinematic spaces, which determine dynamic characteristics

A kinematic space for example is a collision space between tool and clamping space or an assembly space, which determines the necessary space to assemble a part. In Figure 6 there is shown an example of a classification of planning working spaces according to the product-life-cycle stage. Inout and output-constraints of planning-working-spaces are areas of the system boundary which may be penetrated by planning objects like a tool space.

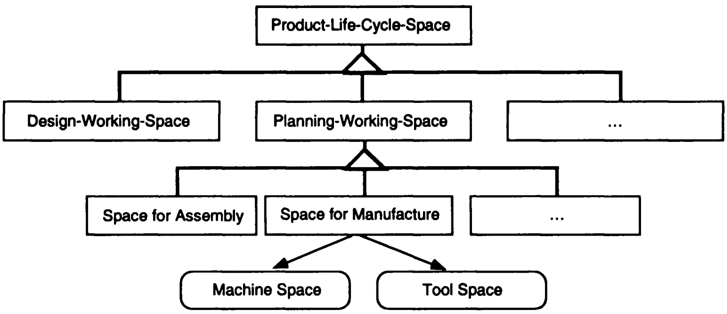

Figure 6 Classification of Planning Spaces

5 MODELING EXAMPLES

In Figure 7 there is given an example of an embodiment design. To fulfill a given product function only the effective-geometry is important (view of design), here an effective surface (Figure 7(1)). Because of the established micro-geometry and the material of the effective surface the production technology of grinding is pre-determined.

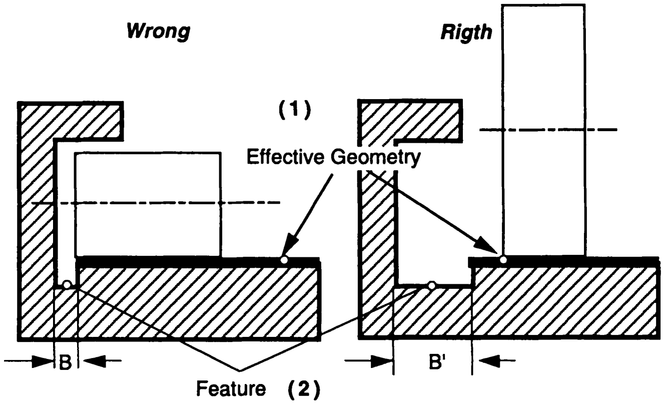

Figure 7 Design guideline for unimpeded grinding by appropriate selection of surfaces

The problem is if the designer wants to design the space for an unimpeded grinding, he models for example a manufacturing feature (Figure 7(2)). In this case he determines the production technology. A better solution would be if the designer specifies a design-working-space *to give free space* for the grinding *tool* not constraining the production technology but the functionally and physically relevant spaces and surfaces (Figure 8(1)). In doing so the designer is able to concentrate on his work (function and principle solution) and leaves the decision for the production technology to the planner. The planner specifies the min./max. tool space which is related to the design-working-space and the effective surface (Figure 8(1)). After that *the planner* defines the embodiment (for example by a manufacturing feature) and determines the production technology for the design-working-space (Figure 8(2)). Because of his responsibility for the general design the designer finally releases the design.

In this example the effective geometry and to some extent the embodiment has been modeled. In the next example only the effective geometry is defined (Figure 9(1)), (*design scope*). In Figure 9(1) there is seen a part of the effective geometry of the robot gripper including the physical magnitudes and the functional relationship. Figure 9(2) shows three planning spaces: one tool space (for grinding) and two spaces for *u*nimpeded *g*rinding (UPG-Space). As in the example above (Figure 8) the tool space is derived by the effective geometry and related to it. The UPG-Space depends only on the production technology (*not* necessarily on the effective geometry) *but constrains the embodiment* of the part which is shown in Figure 9(3). The embodiment of the part (Figure 9(3)) can be generated by a boolean operation between a design working and a planning space. The design working space is generated by a sweep operation along the depicted direction (Figure 9 (3)).

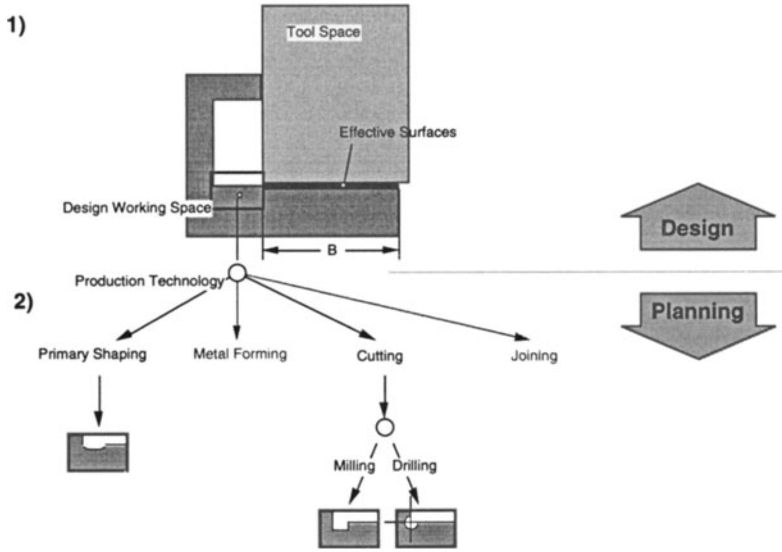

Figure 8 Design for Manufacturing with Design Planning Spaces

6 CONCLUSIONS AND FUTURE WORK

We have modeled and verified the concept of design working spaces with "DIICAD Entwurf"*. Modeling design solutions in design working spaces with the help of solution patterns (Suhm A. (1993)) could be shown for product functions, physical principles and for effective geometry (Grabowski H., Lossack R.-S., Weis C. (1995)). This concept has been implemented on Pro/ENGINEER and [incr Tcl]†, for a distributed design system (Grabowski H., Rude S., Lossack R.-S. (1996)).

To model the product-lift-cycle stages design and manufacturing using an integrated product model in the described way is a promising approach. Implementations have been realized in the scope of the *exchange of not fully specified product data* between the design and manufacturing stage for the evaluation of manufacturability (Lossack R.-S. (1995)). In this case we could reduce unnecessary feed-back cycles

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**DI*alog oriented *I*ntelligent *CAD* System is a prototype system developed at the RPK, *-Entwurf* is a subsystem for Design Working Space Modeling based on the DIICAD product model

†[incr Tcl] is an object-oriented extension to the Tcl language, much as C++ provides object-oriented extensions to C; Tcl stands for the *Tool Command Language.* Tcl and its associated X window toolkit, Tk, were designed and crafted by Prof. John Ousterhout of U.C. Berkley.

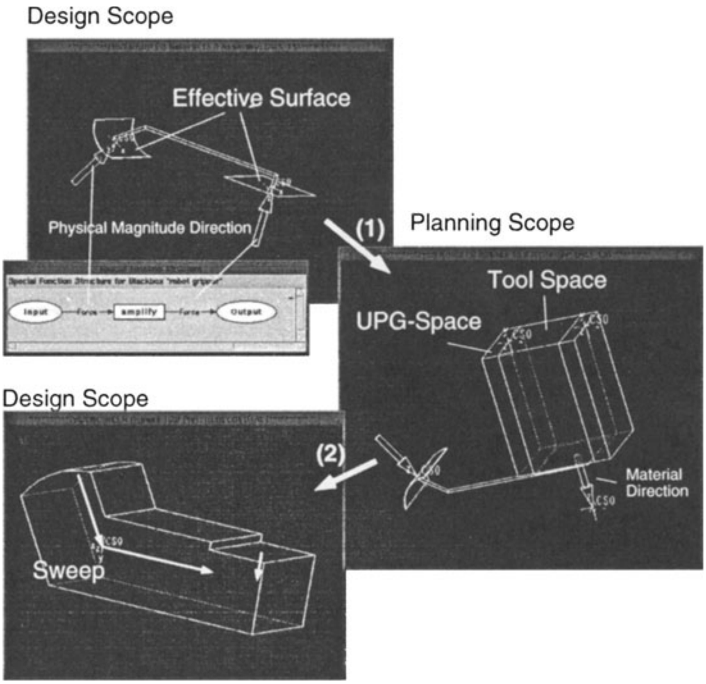

Figure 9 Example of Constraining the Embodiment by a Planning Space

and support both an effective information flow between them and to allow work on the same product at the same time.

We implemented a prototype for modeling features in design working spaces (Grabowski H., Rude S., Lossack R.-S. (1994)) and for constraining the embodiment by planning spaces. The work we have done with the concept of planning spaces is in the beginning, there are problems but we think the concept is a promising approach.

We consider it an important point that in the future basic research has to be done in developing methods for team work with the abstract concept of design and planning working spaces.

7 ACKNOWLEDGMENTS

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