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SIMPLIFYING THE DESIGN OF PRODUCT FAMILIES USING A SEGMENTED DESIGN NETWORK

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1. Introduction

Modern design tasks cannot be completed by a single designer due to the enormous complexity and the number of components of the finished goods. Often the designers do not work in the same office, sometimes not even in the same company. This paper presents a CAD tool representing a segmented design network which allows for several designers to carry out their design tasks collaboratively, even in different locations. For simple design tasks and the very early stage it can, of course, be used by one single designer, too. This tool, the "Active Semantic Design Network" (ASK), supports the designers by various means from the first rough idea until the finished CAD and rating model. All the information in the system is shared between the designers, enabling them to work on their actual design tasks, thereby always keeping in touch with the entire project. This design system is now being extended to support the designers in creating product families derived from single models.

2. The ASK

The concept of the Active Semantic Design Network can be subsumed as follows:
Firstly, according to phase one of [VDI 1993] and [VDI 1977], the actual design task has to be clarified depending on the market demands. The requests and limitations as well as the tasks to be carried out build the basis of all following steps. They are often not yet precisely defined or are subject to later changes and are recorded in the list of requirements on top of the modelling surface, Fig. 1.
When the list of requirements has been filled with all the information available at the moment, concepts are derived, described and rated. Different concepts may be kept for later comparisons. The result of this step is a basic function structure with many degrees of freedom regarding the later implementation.
This function structure is then transformed into an outline of the technical realisation, again potentially incorporating several different possible concepts for parts of the task, e.g. a worm vs. a spur gear drive. In this step, formulas and semantic connections between the parts are added to the parts to create the semantic network which allows for automated recalculations after minor changes and the propagation of changes through the entire model.
In the last phase the outline created before is worked out, dropping all variants and specifying every part in detail. For product families, the variants of the actual family are worked out whereas different design approaches created in phase three are dropped.
These four phases require different tools to support the designers which are combined in and controlled by the program. The basic surface offers the drawing space for all phases and the buttons to control the program. Depending on the functionality needed different third-party and self-programmed tools are called, e.g. the CAD-Software Pro/Engineer for visualisation and optical collision detection.

The phases can be displayed all at the same time or only the desired ones to reduce the complexity and make it easier to follow the construction process. The view of the technical realisation can be zoomed to show only the main structure or more details up to every single screw. Also, the display of connections and relations between the parts can be turned on and off to simplify the navigation in complex design networks.

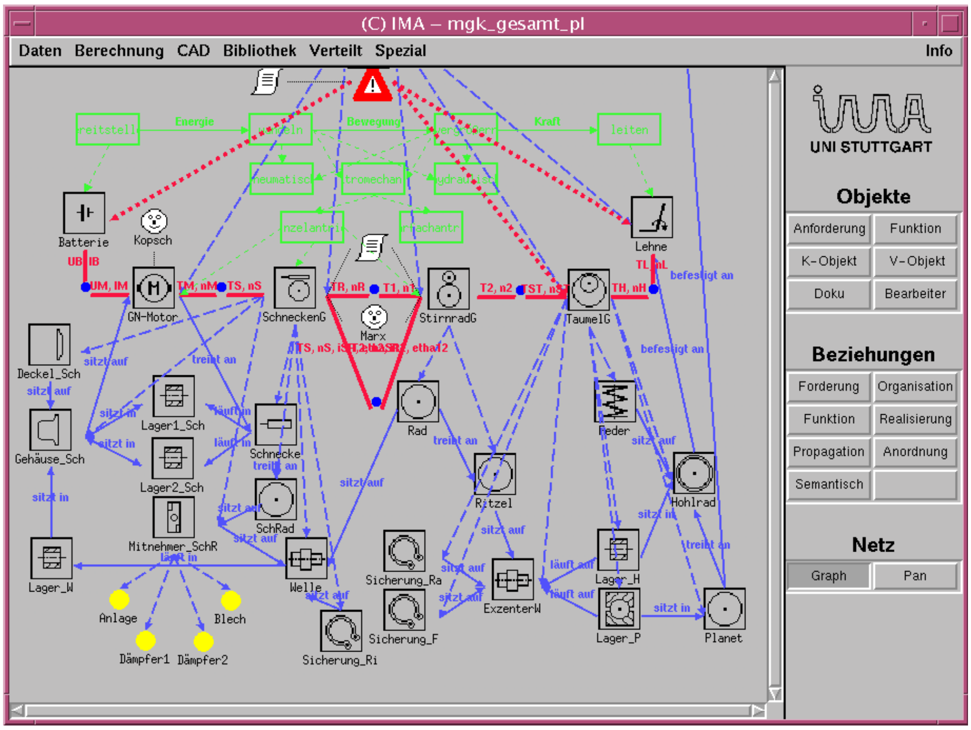

Figure 1. Screenshot of the Active Semantic Design Network main workspace

Since in the early phases of the design process the information about dimensions is usually quite vague, the system allows the use of intervals instead of discrete values. These intervals are narrowed during the design process until they finally lead to discrete values.

To create a design model, the designers use modules representing the actual parts and connect them by semantic relations like ”mounted on”, ”drives” etc. The resulting semantic network is the basis from which the rating and CAD model are derived automatically, thus exonerating the designers of time-consuming and superfluous routine work.

While the designers set up the semantic network, the active component forwards all new information through the net and thereby supplies all designers with the most recent rating results and helps to narrow the intervals set up before due to further external influences.

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3. Segmentation Functionality

The segmentation functionality of the Active Semantic Design Network (ASK) is based on a Client-Server-Structure, Fig. 2. Each Designer uses a client which is connected to a common server process via a TCP/IP network. The server controls the access to the database holding all design information as well as the information shared between the clients. It co-ordinates the requests by the clients and the communication amongst them.

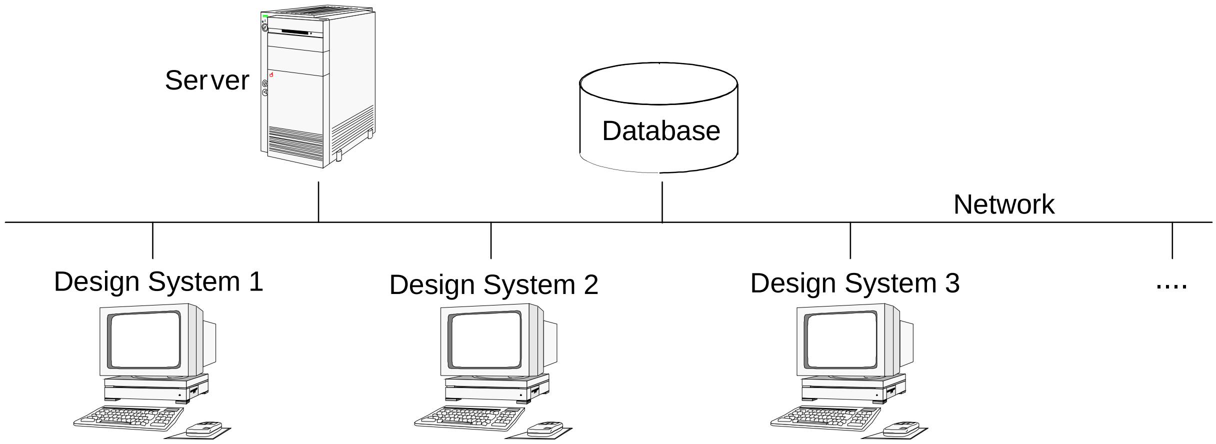

Figure 2. Structure of the segmented ASK

When a designer starts working on a part of the design task or creates a new part, he locks this part and its interfaces so that other clients can read the information but no longer change it. After completing his task or when he considers it suitable, he starts an update procedure which checks if the parts other designers are responsible for are affected by these changes. If so, the corresponding designers are informed and they can discuss the changes using the tools incorporated in the ASK, for example videoconferencing and shared whiteboard. After they all accept the change, the new status is set as current and forwarded to all clients.

This procedure is more suitable than forwarding every change [Schmidt 1993] since sometimes a set of changes gives a variant that has no impact on the other parts whereas each individual step produces a more or less senseless meta-system that is changed in the next step. Furthermore, this technique makes it possible for a designer to create variants and check their effects on the rest of the design without disturbing his colleagues.

To be able to restore the previous state and to share the changes made with the other designers, several copies of the designed network are used. The most important one is the basic network that represents the last status accepted by all designers and finally the completed design. When a designer starts working, he obtains a personal copy of the basic network to which his changes are saved, the so-called modification network. When he considers it suitable, he forwards his changes to the other designers using the update procedure described above. To check other designers´ changes with their own work, the designers use a testing network which combines the personal modification network and the changes forwarded by the update procedure. If this testing network works for them, the designers accept the changes and the system works the modifications into the basic network.

These different networks are handled in the background by the clients. The designers only see the relevant representations. The functionality to communicate with the server, to set and change access rights and to forward changes is supplied via a menu in the main workspace of the ASK.

4. Semantic Modelling

A design model based on a semantic network implicitly contains component-spanning calculation regulations and component alignments in semantic relations between the machine elements. Thus the designer's intention is quite clear when defining a semantic relation for example between a shaft collar and a spur gear or a shaft collar and a bearing. Cases requiring further information due to existing degrees of freedom, e.g. the way of linking a shaft collar with a pinion or a wheel, can be detected by the design system which then inquires the designer.

That way a design system can context-relatedly derive all necessary calculation regulations for the interactions in effect during the constitution of the component relations. These are automatically implemented in the component-spanning rating model, cf. fig. 3. Concurrently, it identifies the topological connections between the machine elements by means of the semantic relations and defines them in the CAD-system. After creating the semantic net the draftsman has a firmed contruction model for components and their interactions at his disposal that he can immediately apply for rating calculations. The CAD-model is available for further refining without restrictions instantly after coarse rating.

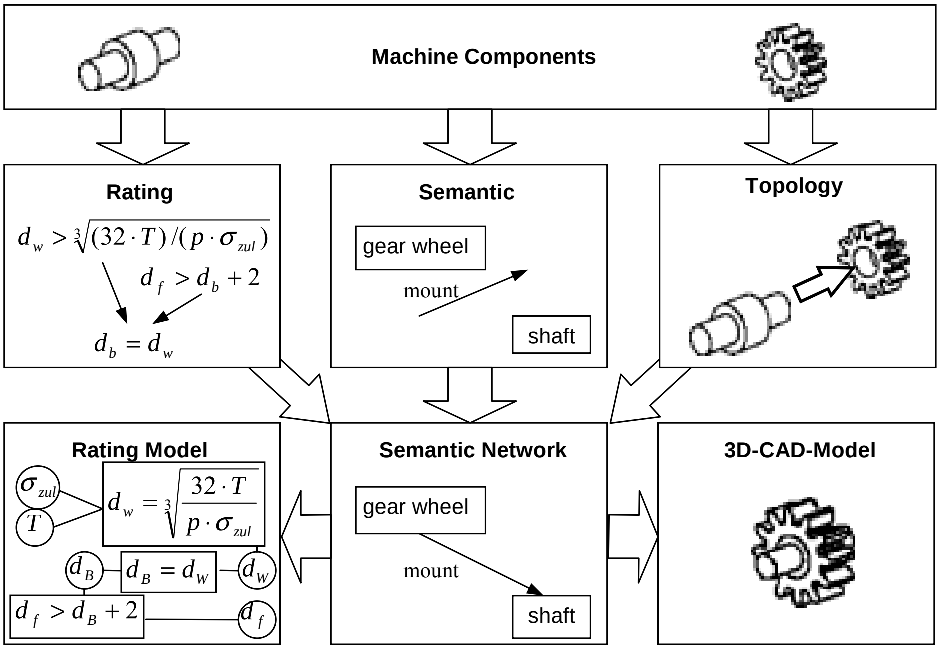

Figure 3. Semantic Modeling

This construction system is based on an active semantic network (ASN) [Hirschmann 1995]. The ASN consists of different types of objects and relations which store, among other things, parameters and formulas for ratings. These parameters and formulas are linked within the object but not with adjacent objects. The reciprocations among the objects are generated manually during the semantic modelling.

In the CAD-system, assemblies are created by grouping components. The position relative to the adjacent components is stated for each component by different means of geometrical conditions, so-called constraints. Usually three constraints are sufficient to determine the position in all three coordinates.

5. Product Families

Since the beginning of industrialization it has been a goal to reduce manufacturing costs by reusing designs and components while meeting the market demands which include an increasing number of variants.

There are two approaches: *Modular Products* consist of standardised components that can be combined in various ways to comply with a given task. Each module fulfils a special function, but the modules have common connectors to mount them. Common expamples of modular products are wall units and machining centers that are usually built on demand using prefabricated modules.

This article deals mainly with the second approach, *Size Ranges*. A size range is defined as a number of artefacts that:

- fulfil the same function,
- are based on the same solution principle,
- are made in varying sizes and
- involve similar production processes [Pahl/Beitz 1996]

If modules of a modular product have to fulfil the same function in different ways, a size range can be incorporated into a series of modular products. This is often the case for motors and gearings.

When designing product families, it is important to choose the right number of members of the family and suitable steppings between them. This is not only a design question but also often an economical issue [Kühborth 1986]. Two aspects are most important when designing size ranges: the geometric similarity of the parts and the steppings according to decimal-geometric number series.

5.1 Similarity Laws

The members of a product family should have common looks, only differing in size or parameters. Usually, a product range is developed by designing one *basic design* from which the others are derived by scaling. Those *sequential designs* have the same structure and looks as the basic design, but their parameters are stepped up. This does usually not lead to satisfactory results unless further conditions are met. Rather than stepping up the geometric proportions, the relative stress should be kept equal. This implies that the same materials should be used, the same technologies should be applied to them and the same level of material utilisation should be archieved.
Similarity is defined as a constant relationship of at least one physical quantity in the basic and sequential designs. The most obvious relationship is geometric similarity: $\varphi_L = L_1 / L_0$ with L_0 being any given length of the basic design and L_1 the corresponding length of the first sequential design. The length of the n^{th} design would therefore be $L_n = \varphi_L^n L_0$.
These rules apply to all members of the size range for - ideally - all parameters desived form the SI System, in detail length, time, mass, electric current, thermodynamic temperature and luminous intensity. Since this is generally neither useful nor possible, the most important parameters have to be stepped up exactly while the others are modified to match. Apart from these basic similarities, special similarity relationships can be useful for design tasks. Those are kinematic (speed/acceleration), static (relative force) or dynamic (kinematic and static) for common mechanical design tasks.

5.2 Decimal-Geometric Preferred Number Series

By appyling similarity laws you can get any stepping, which is usually not desirable. For technical products the parameter steppings should obey to decimal-geometric number series. A such series is developed within one decade, thus fitting into the decimal system. The factor φ discussed before can be generated using the formula $\varphi = \sqrt[n]{\frac{a_n}{a_0}} = \sqrt[n]{10}$, where n is the number of steps per decade. For the common series R10, that is the series of ten steps per decade, this would be $\varphi = \sqrt[10]{10} \approx 1.25$.
Most mass products sold in varying sizes, for example resistors, today are stepped up using one of the four series of preferred numbers R5, R10, R20 and R40.

6. Product Families in the ASK

To create a product family in the ASK, one master model is developed from which the other models are derived. The designers can either change parameters of parts of the existing model or replace parts by other ones, either picked from a built-in catalogue or newly created. When creating a modular product, the modules have one or more common connector(s), usually thom the parts library, but are otherwise entirely different. For Size ranges, it can be more efficient to use standardised parts form the parts library rather than changing the parameters manually. This is especially the case for gearings. Still it is a size range and no modular product. For the ASK, there is no difference between the two since the procedure can be the same.
An important aspect especially for size ranges are suitable parameter gradations. The tool supports the designers in finding standardised decimalgeometric parameter values according to R5 to R40 as well as in scaling the master model correspondingly for each model of the family. If none of the preferred number series works, e.g. because there are too few steps per decade, the designers can manually pick a factor or enter all values manually. For each sequential design, the calculation model has to be checked seperately, especially when gearings are involved since number of teeth for a gearwheel has to be an integer.
All models of the product family can easily be controlled at once thus minimising the potential for discrepancies between them in their common aspects.

7. Conclusion

To meet the market demands, it will be more and more important to faciliate and speed up the design process of products and product families. The Active Semantic Design System offers an efficient means to design single products and product families from the first idea to the finished models. The designers can carry out all steps of the design process collaboratively in one system.

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