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AN OUTSIDE-IN APPROACH FOR PRODUCT ARCHITECTURE AND DESIGN

Berkun Culha

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1 Introduction

Industrial design is essential for Product differentiation in the market. Due to global competition, manufacturers of high-tech products face increasing difficulties to stress out differentiation characteristics within functionality, quality and cost. In many branches products have reached a common level of functionality and quality. Some product groups, for example consumer electronics, have reached a high level of functional complexity that buyers cannot choose by reasoning. More and more buy decisions are made through aesthetic fascination, emotional appeal of the product shape as well as the image of the brand. This is becoming true even for industrial goods. The consequence of this trend will be the growing dominance of industrial design in product development. This paper presents methods and strategies that help to redesign products from outside-in. The objective is to help engineers and industrial designers to validate component layout concepts and pre-estimate the effects of exterior design changes on the engineering solution.

2 Description of Methods

Today's approaches to embed industrial design into the development process of complex products have unwanted limitations. The starting basis of the new project is the predecessor of the product. The product architecture, arrangement of components and assemblies, major spatial constraints are not questioned adequately. The industrial design departments lack the engineering capabilities to push substantial changes in the product architecture and are therefore limited in their freedom to realize extensive stylistic advances. Thus, for the definition of the outer shape the industrial designers are subordinates, which cuts the companies chances to break away from evolutionary shapes and designs.

Most design processes and methodologies are led by the idea to develop functionality and derive the shape of the product from the engineer's constraints. This is the dominating inside-out approach for the generation of complex products. The reverse approach, deriving engineering solutions from shape limits is mainly based upon personal communication of engineering and styling issues in a seesaw manner.

The desired design process should be a blend of inside-out and outside-in procedures. Beside some approaches like product architecture layout planning [1] and assembly arrangement [2,3], the power of the outside-in thinking is poorly explored in scientific and analytical ways.

A design methodology that supports engineering design to follow the outside-in path would enable companies to go new ways. The capability to change the exterior design of the product swiftly with a minimum of engineering effort means a head start. The image of brands and the corporate design can be adapted more quickly and actively to dynamic market changes. Manufacturers have the chance to place their emotional appeal of their products very accurately in the market, fine tuning a mix of conservative evolutionary design and radical changes.

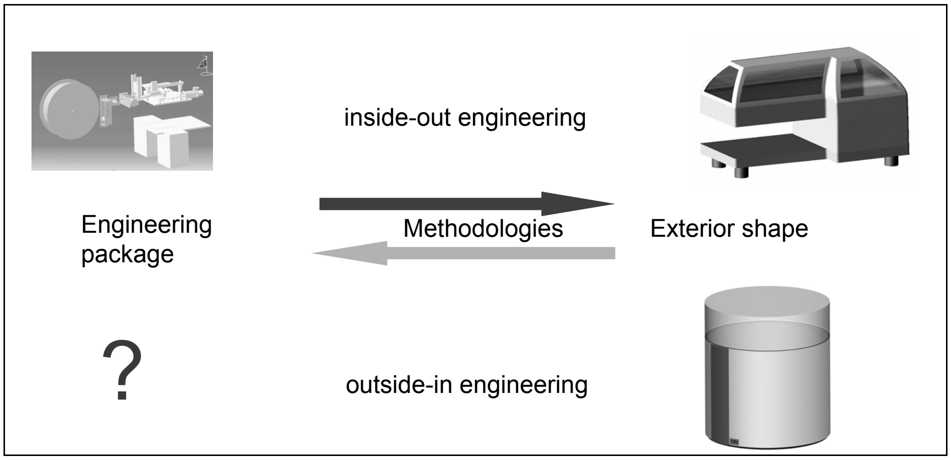

Figure 1. Outside-In approach for product architecture and design planning

2.1 Layout Design in Design Methodology

The form of the complete system is determined by the variation of form and arrangement of the main elements. The form and arrangement of components is being elaborated during the embodiment design phase. This phase includes the overall layout design (general arrangement and spatial compatibility) and the preliminary form designs (component shapes and materials). Furthermore, the production procedure is determined and the auxiliary functions are designed [2]. The first step is to identify the requirements that are crucial for the embodiment design. These are size-determining requirements (e.g. output, through-put, size of connectors), arrangement-determining requirements (e.g. direction of flow, motions, positions) and material-determining requirements (e.g. resistance to corrosion, specified materials, service life). Production and assembly issues, like any other category of specification, may affect these requirements. The second step is to acquire the spatial constraints (clearances, axle positions, installation requirements) of the embodiment design. Afterwards, a rough layout of the embodiment-determining main function carriers is being produced. This work package concretizes the size, arrangement and shape of the components in the subsequent steps [2].

While design methodology above focuses on the development of new products, most of the industrial cases are characterized by further restraining conditions. The increasing complexity of industrial products comes along with advanced modularization and specialization inside the value chain. Cost pressure and shortening life cycles leads to reuse of proven solutions and components. Another complexity driver is the configuration and arrangement of product variants.

The feasibility of a certain arrangement concept can be anticipated by checking the geometrical partitioning, spatial concerns of production assembly and inspection. It is obvious that even with a few components involved, the number of possible arrangement combinations reaches hundreds [4]. With no methodical support the engineer has to deal with all the spatial constraints and simultaneously anticipate all the connected design efforts [5]. The DMU-space-analysis tools available are predominantly for the use in later stages of design and give no methodical support for the synthesis of arrangements. The task of synthesizing and optimizing arrangements needs a new range of methods and tools. The engineers need help to simulate the vast array of possible arrangement concepts, to experiment with spatial constraints and to reach a verifiable optimum [5]. The aim is to provide a powerful decision support tool for laying out the product architecture.

2.2 Position-Dependent Requirements

The synthesis and variation of arrangements begins with requirement-based derivation of arrangement constraints. To acquire the arrangement-determining requirements, a new view on requirements has to be generated. In this view the focus is on the components' position-depending requirements. To generate this view, the relevant requirements for a component (parts, assemblies, modules, sub-systems) can be gathered following this schema:

- Position and relative alignment constraints
- Dependencies within the system environment (neighbours, connectors)
- Requirements of the element considering its environment (space needed, fixing, environmental conditions)
- Requirements of a vacant position considering the possible element (available space, support structures, tolerated emissions)

Furthermore, some requirements deal with the positioning of all elements inside the complete system (e.g. centre of gravity optimization). These requirements are the starting point for the determination of the spatial constraints. They provide a model for arrangement relationships between elements, space zones of common properties and optimization criteria.

2.3 Modelling of Arrangement Constraints

The conception of a tool to simulate possible arrangement concepts needs a spatial conflict solver. The first step is to formalize the position-dependent requirements. CAD Systems offer basic constraints like contact, offset, congruency, clearance and the possibility to reduce the degrees of freedom of solids in their assembly modules. For the purpose of arrangement optimization, new constraint types have to be generated additionally. The arrangement constraints are:

1. Regular assembly constraints (Fixed Position, congruency, contact, offset): characterized by limitations of degrees of freedom;
2. Clearance: characterized by free space surrounding a solid;
3. Enforced neighbourhoods: elements that need to be close to other elements, though no explicit connectors exist;

4. Exclusive neighbourhoods: elements that must not be close to other elements;
5. Enforced positioning zones: elements that have to be positioned in certain zones;
6. Exclusive positioning zones: elements that must not be positioned in certain zones;
7. Partial tolerance of spatial conflicts: elements that can be easily redesigned, modified or replaced by others regarding form and extension (solids with selective collision tolerance).

The transformation of requirements into arrangement constraints can be a time consuming process. Experienced engineers have to work through all the elements for their position-dependant requirements. Depending on the product's complexity, modularization and structural variations the level of detail can include parts, assemblies, modules and sub-systems. The formulation of the arrangement constraints is another elaborate abstraction step. However, once this task is accomplished, a reusable set of computable constraints has been generated. This set can be adapted for all variants, similar products and successor designs.

2.4 Spatial conflict resolution strategies

After all elements are positioned according to arrangement constraints, there are still conflicts unresolved on the one hand, various possible positioning alternatives on the other hand. This shows the need for spatial conflict resolution strategies and layout optimization criteria. The following concepts are needed for the synthesis of an arrangement:

1. Prioritization: Which elements are positioned first?
2. Collision solving: How are the elements moved away?
3. Alignment: How are the elements positioned? When are rotations applied?
4. Optimizing criteria: e.g. moving all elements to the centre of gravity, cylindrical arrangement.
5. Search for gaps: Which other positions are possible for a certain element?
6. Redesign efforts: Adaptation and redesign effort assessment of the elements for the proposed arrangement [5].

The introduced concepts have different degrees of difficulty for algorithmizing. Especially processes like the prioritization of main functional carriers and the assessment of redesign efforts have to be supported with classical evaluation methods.

3 Evaluation

The author is working towards the integration of the aforementioned concepts in his approach in a DMU-tool. The tool will be capable of synthesizing arrangements of product parts, assemblies and modules. The input data for the software tool are the arrangement constraints as well as preferences regarding the spatial conflict resolution strategies. The output is an arrangement concept, either successful with all the constraints satisfied or unsuccessful with displaced components. A first research software prototype has been finished, as an add-on to CAD-software. The prototype implements arrangement constraints 1-4 and spatial conflict resolution concepts 1-4 (see. 2.2 and 2.3). The steps of the application are:

- selection of components

- modelling of arrangement constraints and specification object priorities
- selection of resolution strategies and parameters
- run optimization cycle and evaluation of output.

3.1 Test Scenario

The test scenario includes the design space inside the front end of a car. 16 main components (power train, cooling unit, dynamo, battery, air filter etc.) are modelled as simplified solids. The first example has a boxy hood design (hood design 1), the second is chamfered (hood design 2). As an optimization criterion, all components are moved to the centre of gravity of a chosen plane. Figure 2 shows the automatically generated arrangements.

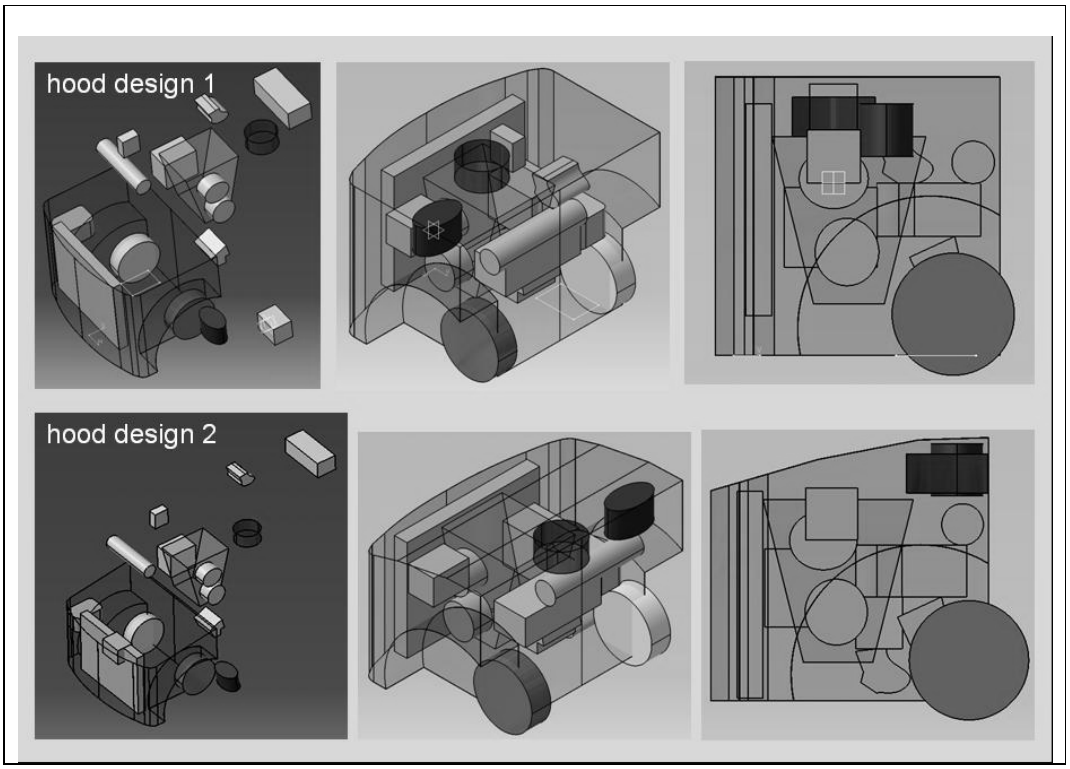

Figure 2. Comparison of simulation results

Table 1 shows a comparison of the characteristics of two successful simulations. The differences display the reduced installation space as a result of the design change. The second test case needed to be modelled with more basic constraints to achieve a successful result, showing a higher need for constraints with increasing tightness.

Table 1. Comparison of case characteristics

case characteristics	hood design 1	hood design 2
filling ratio	31%	35%
basic constraints	8	11
enforced neighbourhoods	3	3

volume ratio: installation space/volume of top 1/3 highest prioritized components	19%	22%
volume ratio: volume all components/volume of top 1/3 highest prioritized components	63%	63%
available degrees of freedom (translatory)	56%	50%

3.2 Future work

The software prototype proves the feasibility of the developed approach. A lot of debugging and further implementation is needed to support a realistic setup for automotive industries. The next step is to achieve more stable version and implement features 5-7 for arrangement constraints and 5-6 for spatial conflict resolution concepts (see. 2.2 and 2.3). Afterwards, the aim is to handle real complex CAD-parts and increase the efficiency of the positioning algorithms. Another work package is the development of a top-level control for intelligent switching between different solving algorithms. This step needs extensive experimental work on arrangement synthesis and verification. Another big challenge in future is the adaptive placement of cables, tubes and other harness components.

4 Conclusion

The increasing complexity of products asks for new design methods and tools. Drawings and 3-D models eyed by an engineer are not sufficient to validate arrangement concepts in future. The work done in this area will be another step towards knowledge based assembly design. Future generations of DMU-Software will be capable of routine positioning tasks and collision resolution. This trend will be supported by advanced product templates on assembly level. The limits of algorithmizing lie in the first and last steps, the transformation of arrangement-determining requirements to arrangement constraints and the evaluation of solutions. The approach being introduced generates a set of 3-D layout proposals to help planners decide about repositioning problems and engineering changes due to styling changes. In this context, it’s a DMU frontloading technique to support outside-in design processes. The approach is also applicable for the very early stages, to validate rough layout concepts as part of conceptual design.

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Berkun Culha

University of Karlsruhe
Institute of Applied Computer Science in Mechanical Engineering (RPK)
Kaiserstraße 12 76131 Karlsruhe
Germany
Phone: +49 721 6086632
Fax: +49 721 66 11 38
E-mail: culha@rpk.uni-karlsruhe.de