# Design Catalogues as Knowledge-Base for CAD-Based Design Automation

Paul Christoph Gembarski(✉)

Institute of Product Development, Leibniz Universität Hannover, An der Universität 1, 30823 Garbsen, Germany
gembarski@ipeg.uni-hannover.de

**Abstract.** Roth's design catalogue was developed particularly as repository for engineering knowledge also for the early phases of the design process and as a methodological support for the designer. Design catalogues are not only a simple collection of known and proven solutions for design problems but allow for structuring and prioritizing solutions according to requirements and development goals. In the current article, a knowledge-based engineering environment is presented that combines a computer aided design catalogue and a case based reasoning system with geometric and analysis models. At the example of dust separators it is shown how Roth's design catalogue is used to determine the most suitable separation technique and to access component configurators, e.g. for a cyclone separator.

**Keywords:** Design automation systems · Knowledge-based engineering systems · Roth's design catalogues · Dust separation

## 1 Introduction

Developing technical products is highly complex due to the variety of solution principles and design constraints [1]. Different activities are carried out in this context, e.g., a distinction is made between conception, i.e., the selection of solution principles for a task, and embodiment design/detailed construction, i.e., the determination of the product shape and manufacturing information [2]. There are numerous tools for both activities. One of them, which has been developed especially for the early phase of the development process, is Roth's Design Catalogue (in the following: RDC) [3].

Although having conceptual similarities with catalogue systems known from computer aided selling, the RDC is implemented as knowledge repository which allows designers straightforwardly to traverse from, e.g., customer requirements to functional requirements or solution concepts with their draft determining parameters [4].

Although literature reports about computer aided RDC, only single sources deal with the application of these tools in context of design automation and knowledge-based engineering systems. Thus, the following paper examines the potential of RDC in the case study of a design automation system for industrial dust separators. As a result of


A.-L. Andersen et al. (Eds.): CARV 2021/MCPC 2021, LNME, pp. 645–652, 2022.
https://doi.org/10.1007/978-3-030-90700-6_73

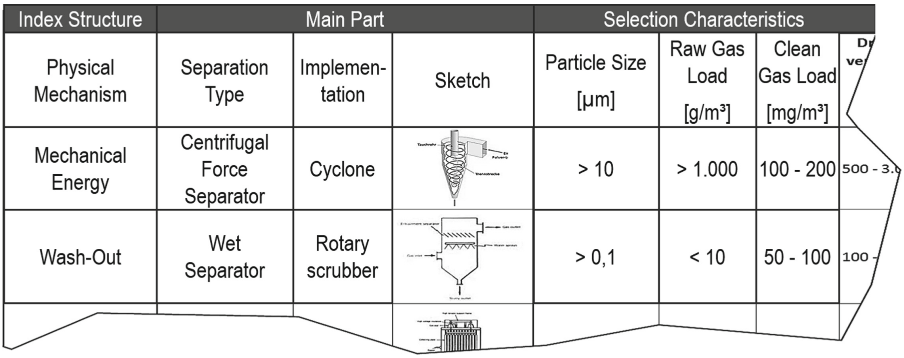
the case study, a platform was created which controls access to individual knowledge-based computer aided design (CAD) models for the respective separator types through the RDC, obtaining the relevant design parameters. The RDC also stores successfully completed and validated configurations in a case base for future accelerated access and knowledge retrieval, so that they can be reused for the same or very similar separation tasks.

## 2 Theoretical Background

### 2.1 Roth's Design Catalogues

RDCs are defined as knowledge repositories which were particularly developed for product development. A special attention was drawn towards the early phases of the development process where the design engineer has to acquire new expertise and use it to methodologically find solutions to the actual design problem [5, 6].

RDCs are organized in tables with one- to three-dimensional index structures. One-dimensional RDC are most common and have a layout with index structure, a main part showing the content and selection/solution characteristics (Fig. 1). The content in the main part can consist of sketches, equations and texts, ideally with a same degree of abstraction [7]. The part containing the solution characteristics is particularly typical for RDCs and should be appropriate to the purpose. As such, the solution characteristics can be used to store and access customer requirements, functional requirements (like in the example shown in Fig. 1, *raw gas load* and *clean gas load*) or draft determining parameters for distinct configurations (e.g. in case of cyclone separators *dive tube diameter* or *depth*).



| Index Structure | Main Part | | | Selection Characteristics | | | |
|---|---|---|---|---|---|---|---|
| Physical Mechanism | Separation Type | Implemen-tation | Sketch | Particle Size [µm] | Raw Gas Load [g/m³] | Clean Gas Load [mg/m³] | Di ve |
| Mechanical Energy | Centrifugal Force Separator | Cyclone | | > 10 | > 1.000 | 100 - 200 | 500 - 3. |
| Wash-Out | Wet Separator | Rotary scrubber | | > 0,1 | < 10 | 50 - 100 | 100 - |

**Fig. 1.** One-dimensional solution catalogue for dust separation systems

RDCs are further divided into four types: *Object* and *Operations Catalogues* deal with closed knowledge areas or methods. *Solution* and *Relationship Catalogues* focus on specific tasks [4]. E.g., they only refer to certain functions or function classes, but describe almost all possible solutions within the set framework. The RDC depicted in Fig. 1 belongs to *Solution Catalogues.*

Approaches to implement computer-aided RDCs have not yet led to widespread application. As long as the RDCs are used like paper-based ones the only advantage is advanced search and filtering. But if the RDC system is connected to, e.g., a CAD system, additional benefit is created since it allows to traverse directly from conceptual to embodiment design by obtaining relevant parameters from the RDC and hand them over to the parametric CAD model [8].

Another existing enhancement is the idea to use a RDC as repository for a case-based reasoning (CBR) system [9]. CBR is the solution of a current problem by using information and knowledge based on similar experiences (cases) from the past and so to reason by analogy. A prerequisite for CBR is the ability to operationalize similarity between cases which can be done with index structures or distance measures [10].

## 2.2 Knowledge-Based Engineering and Knowledge-Based CAD

Knowledge-based engineering (KBE) is a set of techniques to establish product models that are easy to adapt to new requirements and to partially automate design tasks [11]. Many systems thereby focus on activities in embodiment design when the solution concepts are already determined and no conceptual changes occur [12].

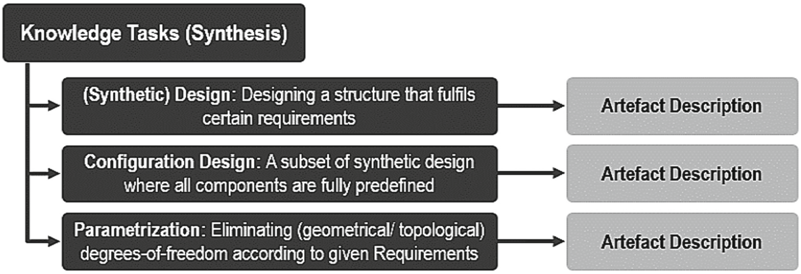



**Fig. 2.** Synthesis tasks delivering artefact descriptions (acc. to [13])

From a task-perspective, KBE systems perform different knowledge tasks that deliver artefact descriptions (Fig. 2). To those belong *synthetic design,* which is designing a system that meets specified requirements, *configuration,* which is assembling a system out from fully predefined building blocks that are matched via standardized interfaces, and *parametrization*, which means to eliminate degrees-of-freedom in a variable product model by setting parameter values [13]. To automatically perform these tasks or combinations of them, a KBE system usually has the ability of reasoning [14, 15].

CAD configurators and knowledge-based CAD models, as instantiations of KBE systems, use this specification as a basis for defining the product shape. In this context, knowledge-based CAD uses functionalities that are available in the CAD system itself, e.g. design rules, equations or constraints. If a design process is fully mapped into such a system and it creates a complete design without the need for further processing or detailing, such systems are also called design automation systems. These may incorporate all three types of synthesis tasks [16].

## 3 RDC-Based Engineering Environment

As stated above, to fully exploit the potential of the RDC, it is necessary to link it with other systems to a computer aided engineering environment. This idea is taken up in this paper, where RDC, knowledge-based CAD templates, analytic sub-models and a case-base are combined (Fig. 3).

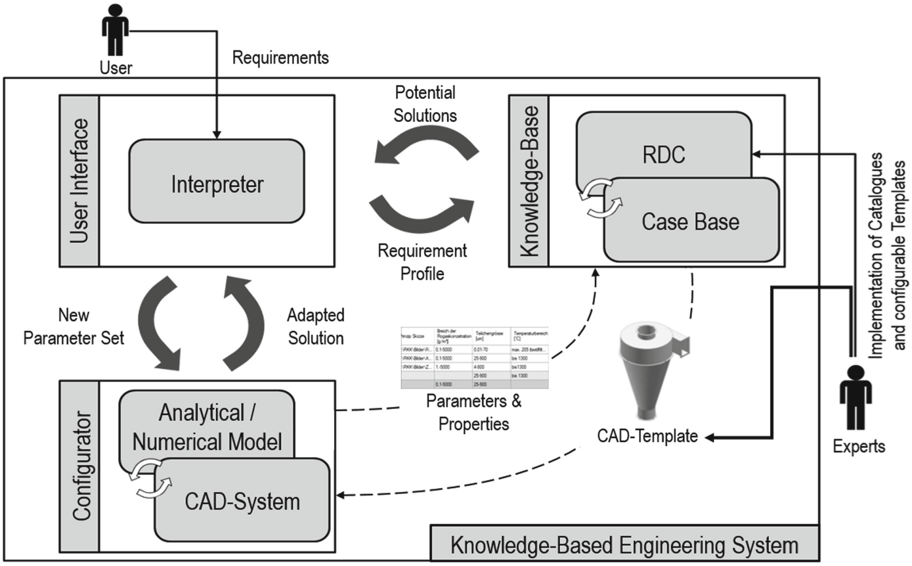



**Fig. 3.** Components of the RDC-based engineering environment

The central component of the computer-aided engineering environment described here is a RDC as part of a *knowledge base*. The RDC generates concepts for the solution of an existing design problem on the basis of a profile either of customer or functional requirements. After entering them into the system, these are first operationalized by an *interpreter* and compared with the selection characteristics of the RDC. To reduce the search space, features can be filtered or weighted according to their importance. After this comparison has been carried out, all potential solutions from the main part of the RDC are presented to the user. The solutions stored here are generic in nature and are not 100% adapted to the entered requirement profile. In parallel, the requirement profile is transferred to the *case base* of a CBR system that is also part of the knowledge base and has a similar structure than the RDC. In the case base, requirement profiles and the corresponding solutions of already solved design tasks are stored in pairs. The solutions are represented by parameter values and links to CAD and analysis models. If the same or similar cases can be found, the corresponding information is extracted and forwarded to the corresponding CAD model. Here, single parameters can be adapted, which leads to a recalculation and adaptation of the geometry. This can be validated in connected analysis models and after validation be transferred to the case base as a new case.

If there is no similar case, the designer can continue working with the generic solutions from the RDC module. Here too, the configuration module is started and a *CAD template* is initialized. This must then be adapted to the case by the designer by setting and optimizing its parameters. Afterwards it is possible to return a validated solution to the case base.

## 4 Application for Industrial Dust Separators

Dust separation is an established and well understood process in plant engineering and beyond to separate solid or liquid particles from gases as completely as possible [17]. There is a variety of different processes for dust separation, which in turn are based on different physical working principles, like wet scrubbing or centrifugal separators. For the selection of a separation system, technical parameters such as the particle size of the material to be separated, static pressure loss, material flow, raw gas temperature or the available installation space have to be taken into account [18]. To implement high-efficiency separators for a defined use case, different models are used to predict the behavior of the separator and discover sensitivities of design parameters on the performance.

The instantiation of the engineering environment for designing dust separators consisted of mainly two activities: (1) the RDC had to be filled with content and (2) the knowledge-based CAD-templates and analysis systems for each separator type had to be implemented. In order to test the system, it was yet chosen to include templates for different settling chambers, cyclone separators and bag houses. All templates are implemented in Autodesk Inventor Professional, parameter control is maintained by spreadsheets and macros, as analysis tools serve, among others, MATLAB/Simulink models.

To start the design of a new separator, the user decides to either enter functional requirements, e.g., particle size distribution and temperature ranges, or customer requirements like dust type, count and types of sources, e.g., wood working machines or welding fumes and operating modes. The case base intercepts the values and checks to what extent such a task has been solved before. If similar designs are available, then these are offered for retrieval. If no solution is available, the system enters the RDC. It then returns which solution concepts are basically available for the specified task and allows comparing them on the basis of the selection characteristics: The user can now also decide which parameters are additionally important, e.g. installation space requirements, exclusion of solution principles (e.g. no wet separators because no additional medium is desired). This can also be enriched by conditions regarding the engineering environment itself, e.g. whether simulation data is available for the selected concept or to what extent experimental validation still has to be carried out.

If the user now decides on a solution concept, the RDC initializes the respective preliminary design models and determines the starting parameters for the CAD templates. These are then transferred to the CAD system and the developer can start detailing or run parameter studies. For cyclone separators, e.g., the depth of the dive tube can be systematically investigated with regard to sensitivities on the separation behavior. To easy access and manipulation, a configuration dialog was implemented where optimizable parameters are instantiated as slider controls (Fig. 4). The results are returned to the case base, so that it contains not only the "good" results but also data for later knowledge formalization. E.g., the case base can be investigated in order to find patterns of useful parametrizations and optimize the starting parameters stored in the RDC part of the knowledge base.

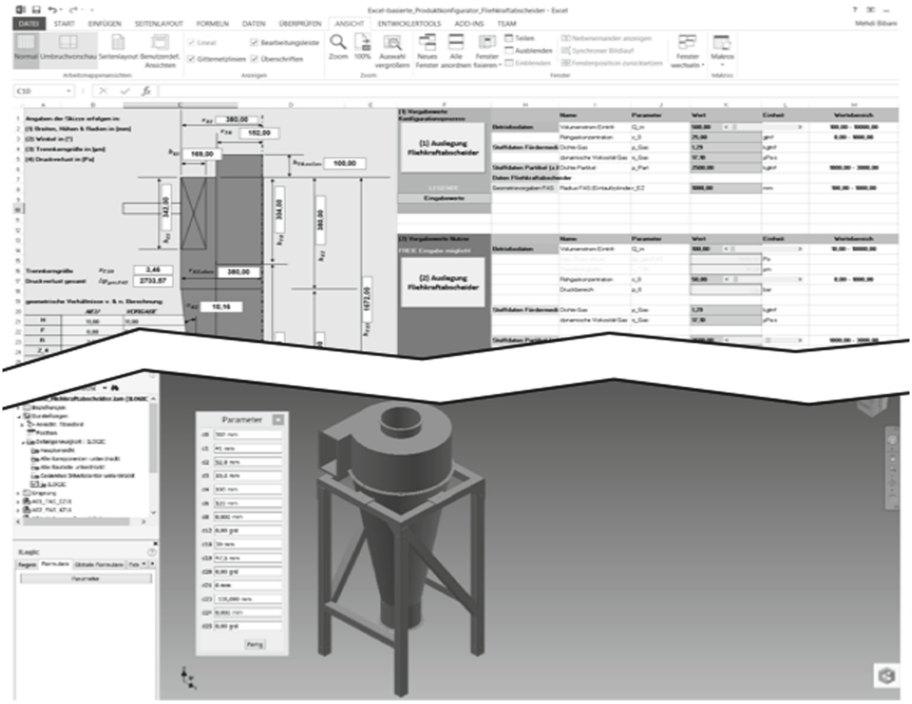


**Fig. 4.** Analytical model and knowledge-based CAD template for cyclone separators

The CAD models themselves also contain various knowledge implementations, like manufacturing restrictions formalized as parameter value ranges or production rules, which ensure e.g. the weldability of the assembly. If such restrictions are violated, the variant is marked as discarded in the case base.

Case base and optimizer communicate before evaluating a new variant and check if a design with exactly the same parameters had already been investigated before. If so, the corresponding entries of the case base are added to the result report without further analysis.

## 5 Conclusion and Future Work

The implemented system allows fast and targeted access to information in various product development phases and rapid adaptation of CAD models through the integration of RDC, case base, CAD system and further analysis models. Conceptual changes are possible at every step of the design process when the designer returns to the catalogue and choses a different suitable separator type. All generated knowledge is stored automatically.

Dust separators can be considered as standard examples from plant engineering, nonetheless there are a few point that reduce the complexity of this knowledge-based engineering environment:

- Linearity of design activities: Although the modeling is in some cases effortful, especially when techniques like CFD are incorporated, and although empirical validation is necessary for many separator types, the design activities follow basically a linear flow. Inputs can be computed to outputs without further considerations of changing constraints and interactions to other components.
- Simplicity of CAD models: The CAD models for the implemented separators involve mostly prismatic and revolved geometry with only little relation between single design parameters so that the implementation of, e.g., manufacturing knowledge is comparably simple.
- Good initial knowledge base: Design knowledge for dust separators is widely available and already formalized to a good degree.

Regarding the stated goal to easily traverse from requirements over concepts to embodiment design and to integrate RDCs as organizer for concept access and knowledge retrieval, the implemented system met the requirements. Especially the integration of RDC and case base showed promising features for the identification of design intent, which in the case study was performed by a human designer. The integration of further algorithmic tools to discover new reasoning is thus an obvious avenue for further research.

## References

1. Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H.: Engineering Design - A Systematic Approach, 3rd edn. Springer, Heidelberg (2007). https://doi.org/10.1007/978-1-84628-319-2
2. Ullman, D.G.: The Mechanical Design Process. McGraw Hill, New York City (2009)
3. Roth, K.: Design Catalogues and Their Usage. Springer, Heidelberg (2002). https://doi.org/10.1007/978-1-4471-3717-7_8
4. Gembarski, P.C., Bibani, M., Lachmayer, R.: Design catalogues: knowledge repositories for knowledge-based-engineering applications. In: Marjanović, D., Štorga, M., Pavković, N., Bojčetić, N., Škec, S. (eds.) Proceedings of the DESIGN 2016 14th International Design Conference, pp. 2007–2016 (2016)
5. Winkelman, P.: A theoretical framework for an intelligent design catalogue. Eng. Comput. **27**(2), 183–192 (2011). https://doi.org/10.1007/s00366-010-0188-4
6. Brockmöller, T., Gembarski, P.C., Mozgova, I., Lachmayer, R.: Design catalogue in a CAE environment for the illustration of tailored forming. In: 59th Ilmenau Scientific Colloquium, Technische Universität Ilmenau (2017)
7. Weiss, F., Binz, H., Roth, D.: Conception of a design catalogue for the development of functionalities with additive manufacturing. In: Proceedings of NordDesign 2016, Trondheim, Norway (2016)

8. Franke, H.-J., Löffler, S., Deimel, M.: Increasing the efficiency of design catalogues by using modern data processing technologies. In: Proceedings of DESIGN 2004, the 8th International Design Conference, Dubrovnik, Croatia (2004)
9. Siqueira, R., Bibani, M., Duran, D., Mozgova, I., Lachmayer, R., Behrens, B.-A.: An adapted case-based reasoning system for design and manufacturing of tailored forming multi-material components. Int. J. Interact. Des. Manuf. (IJIDeM) **13**(3), 1175–1184 (2019). https://doi.org/10.1007/s12008-019-00566-7
10. Richter, M.M., Weber, R.O.: Case-Based Reasoning. Springer, Heidelberg (2016). https://doi.org/10.1007/978-3-642-40167-1
11. Verhagen, W.J.C., Bermell-Garcia, P., van Dijk, R.E.C., Curran, R.: A critical review of knowledge-based engineering: an identification of research challenges. Adv. Eng. Inform. **26**(1), 5–15 (2012). https://doi.org/10.1016/j.aei.2011.06.004
12. Plappert, S., Gembarski, P.C., Lachmayer, R.: The use of knowledge-based engineering systems and artificial intelligence in product development: a snapshot. In: Świątek, J., Borzemski, L., Wilimowska, Z. (eds.) Information Systems Architecture and Technology: Proceedings of 40th Anniversary International Conference on Information Systems Architecture and Technology – ISAT 2019. Advances in Intelligent Systems and Computing, vol. 1051, pp. 62–73 (2019). https://doi.org/10.1007/978-3-030-30604-5_6
13. Gembarski, P.C., Lachmayer, R.: Business models for customer co-design. In: Proceedings of the 7th International Conference on Mass Customization and Personalization in Central Europe (MCP-CE 2016), pp. 76–83. Faculty of technical sciences, Novi Sad (2016)
14. Hopgood, A.A.: Intelligent Systems for Engineers and Scientists. Taylor & Francis, Milton Park (2016)
15. Chandrasegaran, S.K., et al.: The evolution, challenges, and future of knowledge representation in product design systems. Comput. Aided Des. **45**(2), 204–228 (2013). https://doi.org/10.1016/j.cad.2012.08.006
16. Gembarski, P.C.: Three ways of integrating computer-aided design and knowledge-based engineering. In: DESIGN Conference, vol. 1, pp. 1255–1264 (2020). https://doi.org/10.1017/dsd.2020.313
17. Löffler, F.: Staubabscheiden. Thieme, Stuttgart (1988)
18. Peukert, W., Wadenpohl, C.: Industrial separation of fine particles with difficult dust properties. Powder Technol. **118**(1–2), 136–148 (2001). https://doi.org/10.1016/S0032-5910(01)00304-7