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DEVELOPMENT OF A GENERIC INTEGRATED APPROACH FOR PARAMETRIC ASSOCIATIVE CAD SYSTEMS

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ABSTRACT

The automotive engineering process is characterized through a long and complex design activity which starts with first sketches in the preliminary design phase and extends to the final detailed CAD and physical models. Every design phase includes different process steps and tasks which are closely interconnected with each other. The different design stages demand capable Computer Aided Design (CAD) systems which are able to handle the different kinds of design information. Currently one of the possibilities is the application of parametric and associative systems in automotive product development processes. To achieve the full potential of parametric and associative design systems especially in view of the complexity of the CAD parts and assemblies in industries such as the automotive industry it is important to have a clear understanding of how to use such systems best. After a short introduction this paper, which is based on the results of the accomplished descriptive study and literature survey, presents a generic integrated approach to parametric associative (PA) CAD and demonstrates the general requirements of a generic integrated approach. The second section presents the different phases and sub-phases of the developed approach. By means of designing a piston pin the different phases of the developed generic integrated approach will be demonstrated and presented. Section three will discuss the results of the prescriptive study and address the most important issues. In general this paper presents the prescriptive phase of the design research methodology according to Blessing.

Keywords: parametric associative CAD design, integrated CAD method, method development, CAD systems, integrated approach parametric design

1 INTRODUCTION

Today the application and development of methods in engineering design is something natural. The history of design method development is very long and therefore there are many relevant books, theses and research papers in this area. Some of these conventional and general design methods are described by Roth, 1979 [1]; Ehrlenspiel, 1974 [2]; Hubka, 1976 [3]; Rodenacker, 1976 [4]; Pahl and Beitz, 1977 [5]; Koller, 1985 [6]; VDI 2222 [7] and Suh, 1985 [8]. The application and development of the generic integrated approach that will be presented in this paper is defined for a parametric and associative design process in a computer-aided integrated product development environment. According to Ehrlenspiel integrated product development is a *"holistic approach to overcome the problems that arise in product development due to the division of manpower" [2]*. Furthermore, products become more complex and because of that the development can not be accomplished by a single designer. Integrated product development is an approach that includes different methods of problem solving, organizational methods of optimizing interpersonal processes and technical methods for the direct improvement of products [2]. The current situation of integrated product development is based on a stronger interaction and integration of different design activities, groups and departments. These new boundaries and approaches aim to provide stronger support for the individuals (designers and other participants) in the design process during their working process and tasks.

Pahl and Beitz [5] defined the term "method" in engineering design as analyzing the structure of technical systems and their relationships with the environment. Furthermore, the aims of methods are to drive principles for the development of these systems from the system elements and their relationships [5]. They also used the term "methodology" and defined it as a *"concrete course of* *action for the design of technical systems that derives its knowledge from design science and cognitive psychology and from practical experience in different domains"*. This includes the planning of actions to connect working steps and design phases according to content and organization. Furthermore, methods are prescriptive, goal and solution oriented. Methods in the product development process present a kind of guide and advice to reduce the complexity of something [5]. By means of methods, complex problems are divided in smaller sub-problems which can be solved more easily. In addition, methods help achieve better cooperation and communication between the participants in the product development process. The handling and administration of design information and knowledge can also be supported through method application. They also promote the comprehensible documentation of design information in the development process [5].

Method requirements of parametric associative CAD systems based on the descriptive study

The work reported here is part of a programme of research to develop design methodologies that can be applied in an automotive design context by design engineers using parametric associative (PA) computer-aided design (CAD) systems. According to Shah parametric systems solve constraints by applying sequentially assignments to model variants, where each assigned value is computed as a function of the previously assigned value [9]. Unlike procedural systems, the order of the assignments is flexible, determined by a constraint propagation algorithm. The term parametric design in engineering is a process of designing with parametric models in a virtual surrounding (a "parametric CAD system") where geometrical and parameter variations are natural [9]. Related to the design process associativity describes the fixed relationship between geometrical entities and objects. These associative relationships include for example the connection of 3D models and down stream process related elements (such as finite element models, toolpaths and other derived information). In an associative system, any modification in a 3D model is automatically propagated to down-stream applications and connected geometries [9].

The research is being carried out using the research methodology according to Blessing [10]. An important first stage of the study was a descriptive phase to identify the current situation and the important research literature, in part by literature study and in part by questionnaire and interview with practicing designers. The important issues and results which have been achieved during this descriptive study are described in this section, and key results also given in the remainder of the paper. The complete results of the identified challenges and factors are reported in [11]. The literature survey and descriptive study showed the following to be important:

- A specification phase in the model construction process is necessary to achieve an understanding about available parameters and associative relationships between the geometrical entities and objects. The relevant parameters and associative relationships have to be prepared and structured in a clear way.
- Systematic structuring of the design parameters and associative relationships at CAD part and assembly level.
- Systematic identification, determination and classification of the different kinds of design parameters and the associative relationships between the geometrical entities which are relevant in the current design step.
- Systematic documentation of the relevant design parameters and associative relationships between the geometrical entities and enhancement of the transparency and reusability of the relevant design parameters and associative relationships.
- The definition of the relationships between the determined design parameters and geometrical entities (i.e. logical or arithmetical relationships).

This paper presents an approach that has been designed to address these requirements, based on the V-model approach to systems development. In this paper the elements of this approach will be presented, illustrated by examples from automotive power train design.

2 DEVELOPMENT OF A GENERIC INTEGRATED APPROACH FOR PARAMETRIC ASSOCIATIVE CAD SYSTEMS

The following approach is based on three different main phases which comprise the first level of the developed approach (see Figure 1). These phases are: 1) Specification phase; 2) Structuring and creation phase and 3) Modification phase. On the second level of the generic integrated approach there are further six sub-phases, as follows:

1. **Specification phase of the parametric associative CAD parts and assemblies → First level**
   - → *1.1 Identification and determination of parameters → Second level*
   - → *1.2 Identification and determination of associative relationships → Second level*
2. **Structuring and creation phase of the parametric associative CAD design→ First level**
   - → *2.1 Structuring and creation of parameters and associative relationships on part structure level → Second level*
   - → *2.2 Structuring and creation of machined parts on associative assembly structure (Reference part, rough part and finished part) → Second level*
3. **Modification phase of the parametric associative CAD design→ First level**
   - → *3.1 Modification of parameters and associative relationships*
   - → *3.2 Modification of the created structure*

Figure 1 show these phases and sub-phases in diagrammatic form. They are explained in detail in the following sections.

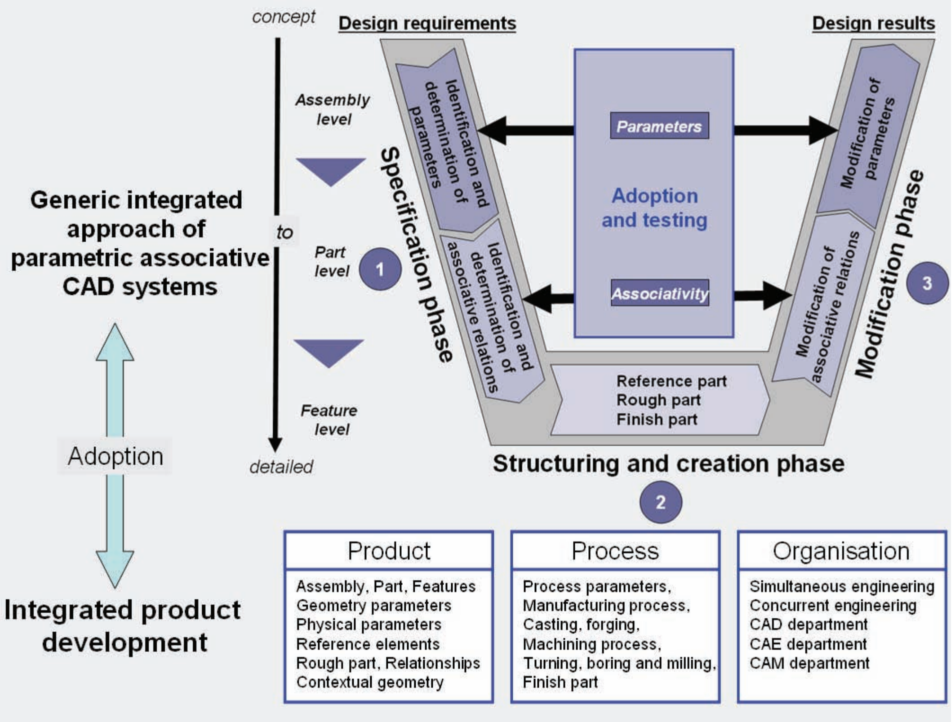


Figure 1: Generic integrated approach of parametric associative CAD systems

2.1 Specification phase of the parametric associative CAD parts and assemblies

The specification or analysis phase is one of the important aspects of the design methods in widespread use. For example, the methods according to Pahl and Beitz [5], VDI 2222 [7] and VDI 2206 [12] contain this important step, and it is the starting point of the developed methods even though the naming of this phase is not the same. Pahl and Beitz described this phase as product planning and clarifying the design task, involving product planning, analysis of the market situation and product proposal. In this phase all product ideas and solutions are defined, identified and determined. The result of all these tasks is the elaboration of a “specification list”. It is necessary to identify, define, determine, structure and arrange the important aspects which describe the product and their sub-elements. The results of these steps are to gain information which can be converted into useful and essential design knowledge. In the case of parametric and associative CAD design systems the results of the literature survey and descriptive study have shown that the working process requires a certain "thinking process" which is necessary to prepare and understand the further steps of the modeling process with this kind of system, and this step is analogous to the specification phase in design processes.

From the point of view of the author the specification of the relevant parameters and required associative relationships needs a fundamental analysis, because otherwise the created CAD parts and assemblies will be confronted with difficulties in later product development steps. This statement has been supported by the fact that 67% of the designers who responded to a questionnaire are of the opinion that it is very important to concern themselves more strongly with the modeling process before starting to design with PA systems and therefore they have to make some preparation how to design and structure their parametric parts and assemblies. Furthermore according to the VDI guideline 2209 [12] working with parametric systems needs preparatory work. Therefore it is important to have a specification phase which helps to identify, determine, structure and arrange the relevant parameters and associative design information which are necessary to design fully PA CAD parts and assemblies. Experience has shown that careful analysis and formulation of problems are the most important steps of the systematic and generic working approach [5]. Furthermore the solution of a problem can be brought nearer by analysis, which is the search for hierarchical structures or logical connections [5]. The developed specification phase of the approach is divided into two different sub-steps. These are a) Identification and determination of parameters and b) Identification and determination of associative relationships. Another aspect which is also important during the specification phase is how to capture the identified knowledge and information during this phase. In conventional design processes, Pahl and Beitz suggest using checklists to document the required information (requirement list) [5]. The selected approach to capture the gained "knowledge" and information during the specification phase of parametric and associative design information is a checklist which in the form of a Parameter Structure Matrix (PSM) and an Associative Structure Matrix (ASM). The definitions of each of these matrices will be given in the next section.

The example which is selected to demonstrate the developed approach is based on the piston pin of an internal combustion engine. The piston is attached to the connecting rod by the piston pin [13]. The pin passes through the piston pin bosses and through the upper end of the connecting rod, which rides within the piston on the middle of the pin [13]. Piston pins are made of alloy steel with a precision finish and are case hardened and sometimes chromium plated to increase their wearing qualities [13]. Their tubular construction gives them maximum strength with minimum weight. They are lubricated by splash from the crankcase or by pressure through passages bored in the connecting rods [13]. Three methods are commonly used for fastening a piston pin to the piston and the connecting rod: fixed pin, semi-floating pin, and full-floating pin. The anchored or fixed pin attaches to the piston by a screw running through one of the bosses; the connecting rod oscillates on the pin [13]. The semi-floating pin is anchored to the connecting rod and turns in the piston pin bosses. The full-floating pin is free to rotate in the connecting rod and in the bosses, while plugs or snap-ring locks prevent it from working out against the walls of the cylinder [13]. The piston pin in the present example is a fixed pin [13]. The next section will present an approach of how to identify, determine and structure the PA design information [13].

2.1.1 Identification and determination of parameters

Parameter is a term that has many definitions depending on the use of the word. The term parameter comes from mathematics and it refers to a factor that controls the values of other factors with respect to a linear relation [14]. According to Shah parametric systems solve constraints by applying sequentially assignments to model variants, where each assigned value is computed as a function of the previously assigned value. Unlike procedural systems, the order of the assignments is flexible, determined by a constraint propagation algorithm [9]. The term parametric design in engineering is a process of designing with parametric models in a virtual surrounding (a "parametric CAD system") where geometrical and parameter variations are natural [9]. In design a parameter is an entity that can hold a value to control geometrical components or relations between geometrical components [9]. Parameters are used to substitute specificity for generality. In CAD, geometrical models are constructed in very specific ways [14]. Parametric design implies the use of declared parameters to define a form. This requires rigorous thought in order to build a geometrical model embedded in a very sophisticated structure appropriate for the needs of the designer. Therefore the designer must anticipate which kinds of variations he might want to explore in order to determine the kinds of transformations.

The results of the questionnaire study that preceded this method development demonstrated that designers have difficulties to identify and determine the required design parameters. For example 76% of the respondents confirmed that during the modeling process they were not able to find the right parameters in large and complex CAD parts and assemblies. Furthermore because of the different kinds of existing parameters many designers are overextended to identify, determine and structure the available parameters in their parametric CAD parts and assemblies. This problem becomes bigger if the designers should change the parameters and geometry of "foreign" components and assemblies (CAD parts and assemblies which are created by other designers e.g. by suppliers). 81% of the respondents agreed that it is quite difficult to change the parameters of "foreign" parts and assemblies, and 86% agreed that it would be very helpful and desirable to have more information about the construction and structure of the parametric associative CAD part and assemblies. The relevant parameters during the design process with PA systems can be classified in four different categories:

Geometry parameters: These are geometry indicators like size, height, breadth, length, and diameter or object properties which classify the product. These parameters are also known as "driving parameters". By modification of driving parameters the generation of a new variant of the CAD model is possible [6].

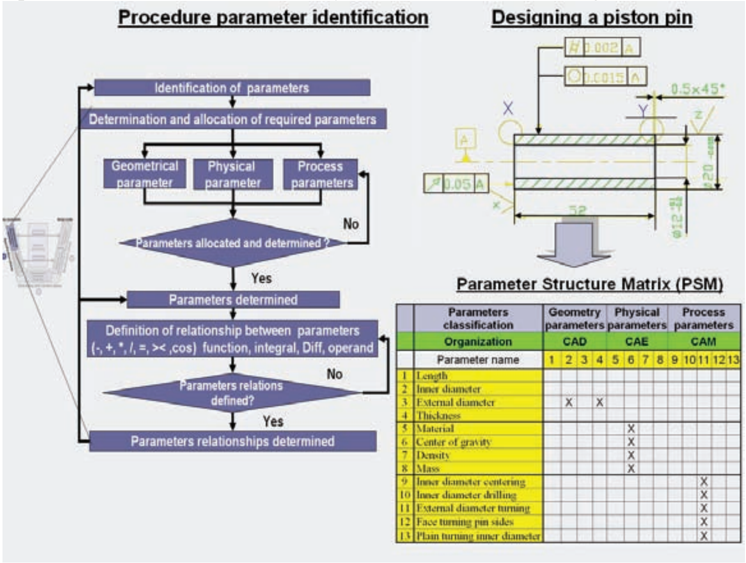
Physical parameters: The physical parameters define further properties of the CAD model. These are e.g. material of the CAD model. Combined with the geometrical parameters the physical parameters can be the basis of calculations and analysis [6].

Process parameters: These are parameters which define the selected process of the selected technology. Process parameters can be NC-processing data or heat treatment requirements.

Non-geometrical parameters: These are parameters which describe the property of the CAD parameters like parameter name, number etc [6].

Furthermore there exist also relationships between the different kinds of parameters. These relationships can be arithmetical, logical and geometrical constraints. Arithmetical relationships are the normal mathematical formula and operations like plus, minus, radical and trigonometric function. Logical relationships can be used in combination of string operations (AND, OR, IF, IF NOT etc.) for representation of different model conditions (i.e. IF D>20 then C=1 else C=3) [15].

The procedure of how to identify and determine the different kinds of parameters during the design process with parametric and associative CAD systems can be taken from figure 2.



	Parameters classification	Geometry parameters				Physical parameters				Process parameters				
	Organization	CAD				CAE				CAM				
	Parameter name	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Length													
2	Inner diameter													
3	External diameter		X		X									
4	Thickness													
5	Material						X							
6	Center of gravity						X							
7	Density						X							
8	Mass						X							
9	Inner diameter centering											X		
10	Inner diameter drilling											X		
11	External diameter turning											X		
12	Face turning pin sides											X		
13	Plain turning inner diameter											X		

Figure 2: Specification phase parameter identification and determination procedure

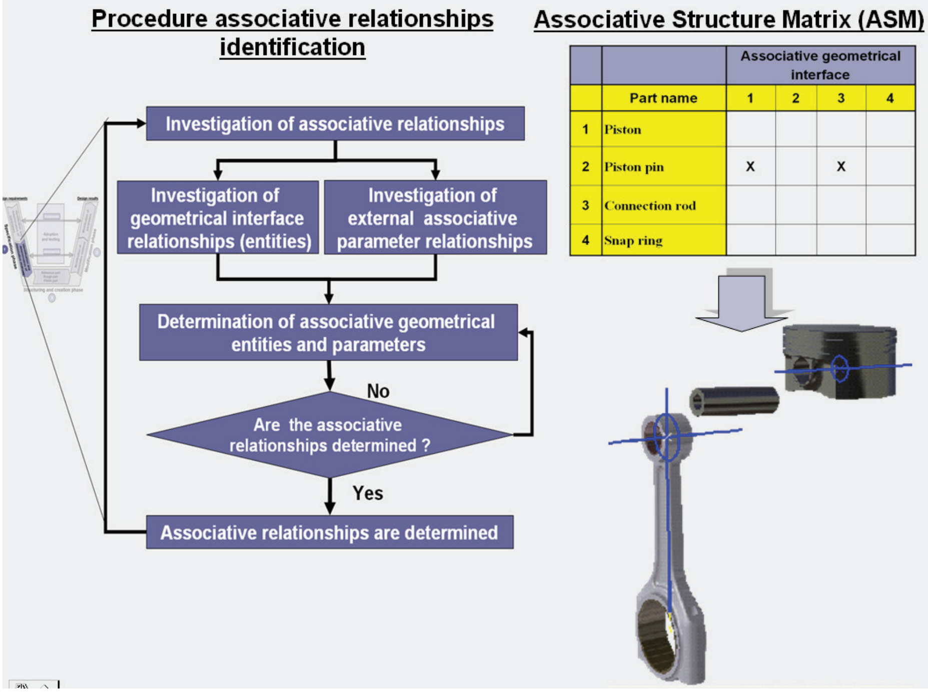
The starting point of the identification and determination of parameters is the definition of all possible parameters in the current design stage. In case of designing a piston pin the parameters which describe the geometrical artifact are the length, inner diameter and the external diameter. Further parameters which are also required for the downstream processes are material, derived weight, density, center of gravity, inertial tensors and contact surfaces between pin and the piston. Furthermore from the manufacturing aspect of the piston pin there are parameters like tolerances, surface finish and process steps (i.e. centering, turning and boring). For a better capturing and collecting of the above mentioned parameters and their relationships to each other a checklist is defined which is based on the **Parameter Structure Matrix (PSM)** (Figure 2). The framework of the PSM is based on the logic and structure of the Design Structure Matrix (DSM) approach [16]. The PSM is materialized as an nxn adjacency matrix of geometry, physical and process parameters with their relationships to each other and with identical row and column headings (Figure 2). Furthermore the defined parameters are clustered (clustering is a valuable technique for examining the structure of a system. The clustering technique applies graph-theoretic cluster algorithms to reorder the rows and columns of the matrix by grouping highly related nodes, called clusters [16]) in three different organizational categories which are CAD, CAE and CAM engineering. These three different categories have been identified during the descriptive study, in which 67% of the respondents agreed that because of the associative relationships between the geometrical entities and downstream processes working with PA systems requires a closer collaboration between design participants.

The DSM methodology emerged in the early 1980s as scholars demonstrated how graph theory can be used to analyse complex engineering projects. Steward showed how the sequence of design tasks could be represented as a network of interactions [16]. A DSM can represent the abstraction of the relations among components of a product, teams concurrently working on a project, activities or tasks of a process, and/or parameters within the system. Furthermore by means of this abstraction it is possible to find a higher level interrelationship, that is, one which is more generic and comprehensive. Such a procedure reduces complexity and emphasizes the essential characteristics of the problem and thereby provides an opportunity to search for and find other solutions containing the identified characteristics. So abstraction supports systematic thinking [16].

The developed PSM approach is used for modeling the parameter architectures based on the different kinds of parameter categories and classes which are available on different CAD parts, assemblies and their relationships to each other. In a PSM the "X" in a cell is used to indicate the coupling and relationships between the different kinds of parameters. By this means designers get a better understanding of the available parameters and are able to plan how to integrate the identified parameters in their created CAD parts and assemblies. In addition, a generic approach is needed to inform the other participants in the design process of the required design parameters. The next section represents the approach of how to identify and determine the associative relationships.

2.1.2 Identification and determination of associative relationships

After the identification and determination of the required parameters it is also important to clarify the identification and determination of the required associative relationships between the geometrical entities. Related to the design process, associativity describes the fixed relationship between geometrical entities and objects. These associative relationships include for example the connection of 3D models and down stream process related elements. (The connections between 3D models and down-stream process related elements are finite element models, toolpaths and other derived information). In an associative system, any modification in a 3D model is automatically propagated to down-stream applications and connected geometries [8]. The product geometric entities include assemblies, components, solids, faces, edges, vertices, surfaces, curves and points. In the literature there are a lot of terms like "Adapter, Skeleton modeling" which describe the associative relationships between the geometrical entities. A skeleton model *"is the framework of a design, and acts as the 3D layout of the assembly. Like 2D layouts, skeletons serve as a central location for storing design criteria relating to the assembly, specifically surface geometry, points lines and curves [17]"*. Adapter and skeleton models simplify design creation and visualization, help to manage relationships and to provide control over external references. The act creating associative relationships between the geometrical entities is also called as "referencing". Therefore the models which contain the basic associative elements are called the "Reference model". In the following paper the author will use "Reference model" to replace all the possible definitions which can be used to describe the models which contain the basic geometry elements (i.e. Adapter and Skeleton models). Reference models contain basic geometrical entities or parameters (i.e. points, lines), are characterized by an exactly defined geometrical interface, use linear associative relations, are hierarchically ordered, can be defined by simultaneous or concurrent engineering teams and are considered as an geometrical interface and touch point to the downstream processes (CAM, CAE). The procedure of how to identify and determine the associative relationships between the geometrical entities and objects is shown in figure 3.



		Associative geometrical interface			
	Part name	1	2	3	4
1	Piston				
2	Piston pin	X		X	
3	Connection rod				
4	Snap ring				

Figure 3: Identification and determination procedure of associative relationships

The starting point of the procedure to identify and determine the associative relationships between the geometrical entities is the investigation of the geometrical interface and determined parameters of the CAD component. For the investigation of the geometrical interfaces it is necessary to analyse the components which are in the surroundings of the created CAD component. The target of this step is at first to identify the surrounding geometry and in the next step to determine the associative entities and objects which are relevant for the creation of the reference model. During the determination of the associative relationships it is necessary to distinguish between geometrical entities which have an impact on the parametric associative CAD component and those which have no impacts on the geometry. There are two different kinds of associative relationships between the geometrical entities. These are “driven” and “not driven” relationships. “Driven” relationships have a direct impact on the CAD components which are based and connected with them. A “Not driven” associative relationship doesn’t have associative impacts to the other geometry and describes only the geometrical environments. In case of the design of the piston pin the relevant parameters has been identified in the step before. Now the geometrical interface analysis should help to identify the important geometrical interface of the piston pin. For a better capturing and collecting of the above mentioned associative connections between the geometrical entities a checklist which is based on **Associative Structure Matrix (ASM)** has been created.

The ASM approach contains the associative relationships between the geometrical objects and entities. The framework of the ASM is again based on the logic and structure of the DSM. The ASM is materialized as an nxn adjacency matrix of CAD parts and associative relations with identical row and column headings. Furthermore, by means of the ASM the relationships between the associative geometrical entities can be clustered. In Associative Structure Matrix (ASM) the "X" in a cell is used to indicate the coupling and relationships between the different associative CAD parts or assemblies which are in the surrounding of the created CAD part. The goal of the ASM is the identification and determination of the geometrical entities which are used in the reference model. In case of the associative design of a piston pin the analysis has shown that there is a relationship between the piston pin, the piston and the connecting rod (see Figure 3). The determination of geometrical entities which describe the content of the reference model of the piston pin is from the piston and the connecting rod. The geometrical entities which have been identified and determined are the position, diameter and horizontal axis of the connecting rod eye boss and the piston (see Figure 3). By means of the ASM approach the different kinds of associative relationships between the geometrical entities can be identified and determined during the design process with parametric and associative CAD systems. In addition the clustering of the associative relationships helps designers to get a better understanding of the available associative relationships between the geometrical entities and in this way designers are able to plan how to integrate the identified geometrical entities in their created CAD parts and assemblies. Furthermore with the ASM approach designers are also able to create the conceptual architecture of their reference model. That means that ASM helps to define and create the reference models on the different level of the complex product structure. In case of designing an associative architecture of an engine the ASM approach helps to identify and determine the relevant associative relationships of the different system levels (i.e. reference model of the valve train, camshaft drive, cylinder head and cylinder block). Furthermore the methodological preliminary working stages of creating associative relationships between geometrical entities can be supported through the ASM approach. The next section of the work presents the next stage of the developed approach which is the structuring and creation phase of CAD parts and assemblies.

2.2 Structuring and creation phase of the parameters and associative relationships

By means of the structuring and creation phase it is possible to structure the identified and determined parameters and associative relationships between the geometrical entities in the specification phase. Furthermore pre-defined CAD parts and assemblies are created to structure the PA design information inputs and outputs. The PSM and ASM approaches presented in the last section help to identify, determine, document and cluster the different kinds of relationships between the geometrical entities. The structuring aspect of CAD parts and assemblies has been one of the important aspects of the literature survey and accomplished descriptive study. 76% of the respondents confirm that during the modeling process with parametric and associative CAD systems because of poorly structured CAD parts and assemblies they were not able to find the right parameters and associative relationships in large and complex CAD parts and assemblies. This problem becomes bigger if the designers have to change parameters and geometry of "foreign" components (these are CAD parts which are designed by other designers or by supplier). 81% of the respondents agreed that it is difficult to change CAD parts and assemblies created by other designers. But the next important point was that 86% of the respondents agreed that in regard to "foreign" components and assemblies it would be very helpful and desirable if there should be a pre defined structure of the CAD parts and assemblies. Furthermore many of the respondents claim that because CAD parts and assemblies are poorly structured they have difficulties to modify them. In addition, the design information which is required by the downstream process partners is also not well structured. The designer appreciates the idea to created pre-defined CAD parts and assembly structures which consider these requirements.

The purpose of structuring technical systems is the decomposition of systems in smaller subsystems and by means of structuring it is possible to reduce the complexity of a system and to concentrate the available information from the environment. In case of parametric and associative CAD design it is very important to structure the identified parameters and the relationships between the geometrical entities. By means of structuring the parameters and geometrical entities it is possible to increase the reusability of the created CAD parts and assemblies. Furthermore because of the structuring of design parameters and geometrical entities, engineering and process partners are able to find the information available in the created CAD parts in an efficient way. The presented approach is based on fixed predefined PA assembly and CAD part structures which have the following goals: a) to increase the transparency of the parameters and associative relationships, b) to increase the reusability of the created parts and assemblies by means of established predefined structures, c) to standardize the structure of the created parametric and associative CAD parts and assemblies for machined components, d) to enable the possibility to structure the determined parameters and associative relationships; e) to define a hierarchical order of the different design information inputs and output; f) to integrate the clustered and classified parameters and associative relationships in the CAD parts and assemblies and g) to enable designers and other design participants to find the required parameters and associative relationships by means of a predefined structure.

The predefined PA structures of the following approach are divided into part and assembly modeling categories. According to Shah the assembly model is needed to make "*some engineering analyses and applications like interference detection between parts, motion simulation, constraint satisfaction, assembly analysis and assembly manufacturing planning" [9]*. Furthermore the information that needs to be captured and represented at the assembly level by an assembly modeler includes the following targets: a) assembly and sub-assembly positions (global or relative coordinate systems), b) mating conditions (i.e. geometrical relationships) and c) hierarchical relations (assemblies, sub-assemblies, components and features) [9]. Positioning information and a system of part spanning constraints is also included. During the modeling process of assemblies there are two different kinds of approaches. These approaches are "top-down" or "bottom-up". A top-down design environment support transitions from high-level, conceptual assembly models stressing the function of the assembly to detailed model of the individual components. The "bottom-up" approach starts with designing a single CAD part on the low level of the product structure [9]. At the end of the design process of the created single components all the CAD parts and assemblies will be merged to a new model or an assembly. That is also the reason why we talk about a bottom up design.

The selected approach of the following work is based on the "top-down" approach. That means that the structures which are predefined are created and given top-down [9]. The starting point of the procedure to structure and create the identified and determined parameters and associative relationships is to identify if the CAD component is a single part or an assembly. After the identification the predefined structure of a CAD part or an assembly can be selected. In the final step the identified design information inputs and outputs which contain the parameters and associative relationships can be arranged and created (Figure 4).

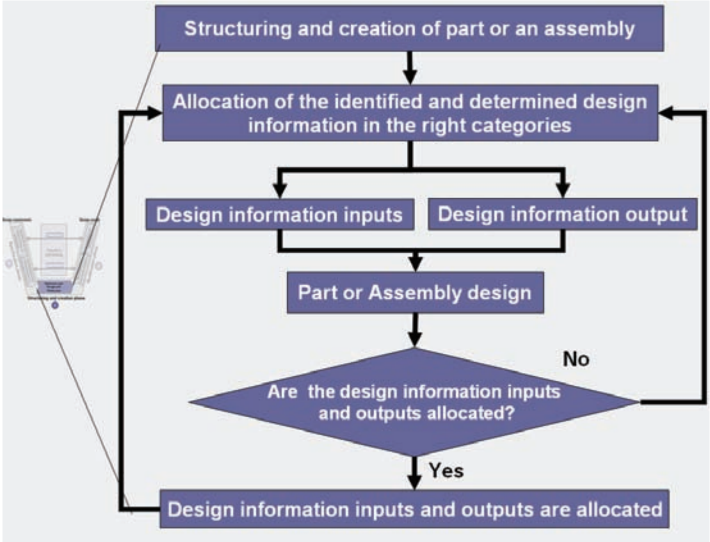


Figure 4: Structuring of parametric associative design information inputs and outputs

The pre-defined structures of the approach are a) Parametric Associative Assembly Structure (PAAS) and b) Parametric Associative Part Structure (PAPS) (see figure 5). The PAAS is based on associative relationships between different CAD parts which represent the hierarchical structure of the designed parametric associative assemblies. The PAAS is hierarchically ordered and contains three different parts which are connected by means of associative relationships. These three parts are 1) Reference model, 2) Rough part and 3) Finished part. The idea behind the three parts is that the designer can work from the conceptual design stage to the more detailed stages of the design process with parametric associative CAD systems. Furthermore the design process participants are able to catch the different parts which are created in PAAS so that a concurrent and simultaneous engineering environment can be enabled. For example manufacturing engineers who are interested in the created rough-part can capture their required parametric model information. Furthermore, based on the designed rough part the machining process steps can be created by the difference between the rough parts and machining components like bore elements.

The first part of the PAAS which defines the associative elements part is the architecture of the conceptual design elements and contains all the technical specifications of the CAD component as well as environmental geometry and constraints (Figure 5). The architecture is a set of logical and parametric features of an object or system that can be used to build the CAD model. Furthermore the reference model contains the input information which describes the basis-element of the CAD component. These basis-elements are axes, coordinate systems, lines, curves, surfaces, solid geometry, parameters, styling geometry and contextual geometry like standard-, purchase- and carry over parts. Furthermore the design engineers are able to modify the designed components by only changing the basic geometry and parameters in the associative part. The second part of the PAAS is the design process of the rough part. The rough part contains the basic geometrical feature information and the assembly of the geometrical features by means of Boolean operations (i.e. union, trim etc.). The last design step of the rough part is the creation of detailed information like the filleting and chamfering information for the CAD components. The third part of the PAAS contains the finished part. The finished part contains all the machining information of the CAD component. Furthermore, the features which represent the machining stages can be implemented in the finished part by means of associative relationships. At the part level there exists also a pre-defined structure which is important for the implementation of the identified parameters and associative relationships.

The next predefined structure is the PAPS which is divided in 4 different parts. These four different parts should help to structure the identified parameters which are necessary for the down stream processes and for the CAD design participants. The first part of the PAPS contains the input information which is necessary to design the CAD components and describes the basis geometry. The input information is associative geometry like points, lines, curves and contextual geometry which describes the geometrical surroundings on the part level. The second part of the PAPS describes the area where the geometry should be created and maintains the main result of the design stage (embodiment area). The third and the fourth part of the PAPS are created to enable the exchange of information which is necessary for the down stream processes. In this case these two areas are CAE engineering and CAM engineering process partners. Figure 5 shows the PAAS and PAPS approach (Figure 5).

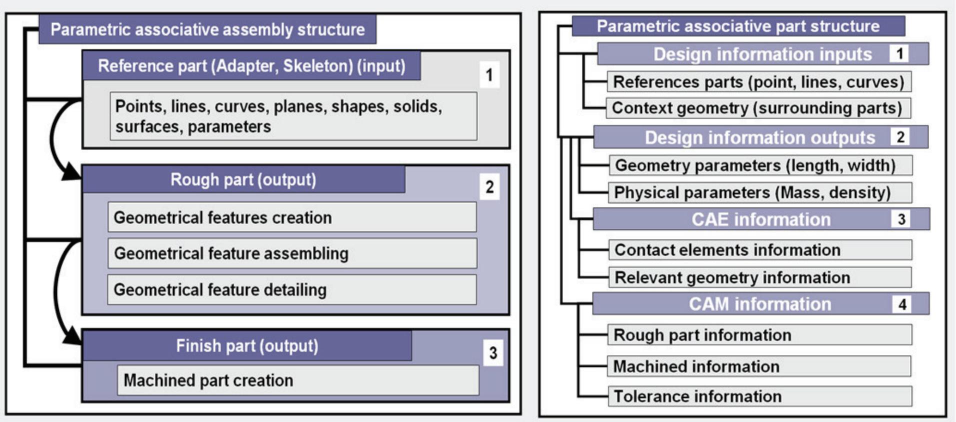


Figure 5: Structuring of design information inputs and outputs at part and assembly level

Figure 6 represents the structuring stages of the piston pin starting with the definition of the reference model which contains the basis geometry like position, external diameter and horizontal axis of the piston pin. Based on the reference model and by means of associative connection the next stage is the design of the geometrical rough part which contains basic features, Boolean assembly of the created features and the geometrical detail information (i.e. rounding and edge trimming). The third stage contains the finish part of the piston pin which is the difference between the rough part and the machine part elements (i.e. turning and boring).

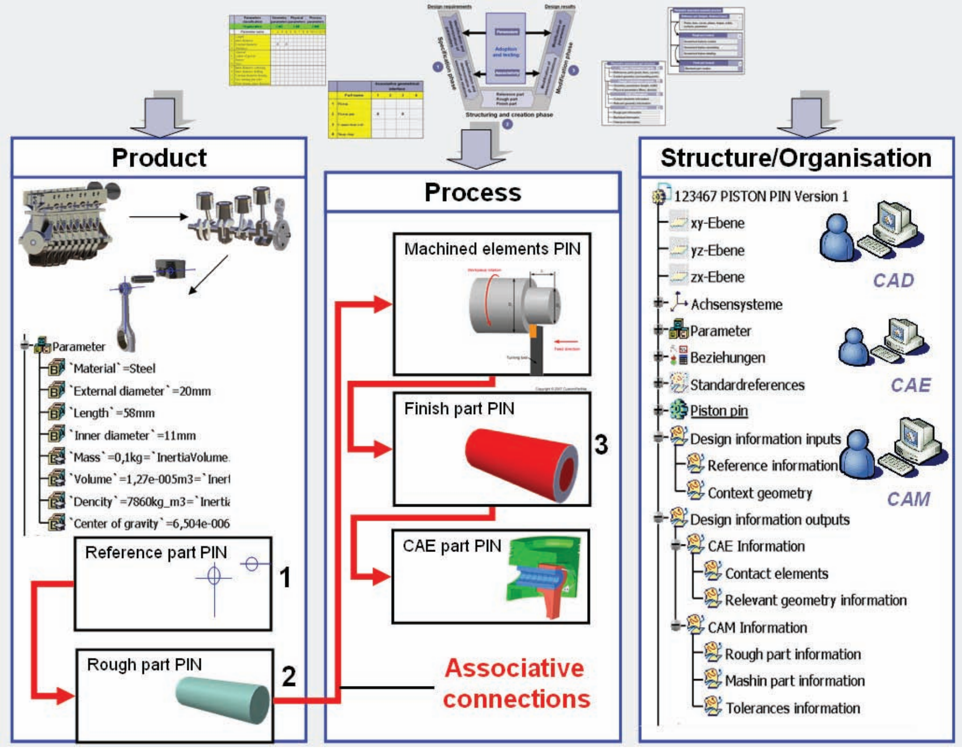


Figure 6: Structuring of design information inputs and outputs

2.3 Modification phase of the parametric associative CAD design

The last phase of the presented integrated approach contains the modification of the created parameters and associative relationships and helps to test and evaluate the created parameters and relationships. The most important point during the modification phase is to check a) the consistency of the created parameters to ensure the created parameters can be changed and the CAD parts and assemblies can be regenerated without failures and b) the consistency of the created parametric and associative relationships between the geometrical entities and objects to ensure that in case of geometrical changes the associative relationships still work.

3 CONCLUSION

The need for a generic integrated approach to parametric associative CAD systems in industrial environment has been identified. In this paper a generic integrated approach which accompanies the designer from the concept to the detail process of the CAD design with PA systems has been identified. The most important stage during the design process with PA design is the specification phase which is the basis of the further design stages. That means that during the specification phase the designer gets an understanding of what to do next and what the important parameters and associative relationships are. The PSM and ASM approach have been presented as methods to identify determine and document the relevant parameters and associative relationships between the geometrical entities. The structuring and creation of the PA design has also been considered. By means of a predefined structure layout of the created PA parts and assemblies it is possible to increase the design transparency, to increase the reusability, to standardize the structure, to define a hierarchical order of the different design information inputs and outputs and to integrate clustered and classified parameters and associative relationships in the CAD parts and assemblies. The presented structuring approaches were based on the PAAS and PAPS models. For the future a tool called "PARAMASS" is planned which should make the presented design steps automatically. Furthermore the developed PA design method will be evaluated and assessed by means of qualitative and quantitative criteria. In addition there will be a "before" and "after" consideration and evaluation of the developed generic integrated parametric associative method.

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