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Development and Application of an Integrated Approach for Parametric Associative CAD Design in an Industrial Context

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ABSTRACT

The product development process in the automotive industry is characterized by long and complex design activities. Currently one of the possibilities to support such activity is the application of parametric and associative CAD systems. To achieve the full potential of such systems, especially in view of the complexity of the CAD parts and assemblies, it is important to have a clear understanding of how best to use them. This paper presents an integrated approach to their use in different phases. After presentation of the results of a literature survey on the field of parametric associative CAD design systems the paper will present the results of a descriptive study I which has been accomplished to identify the challenges, problems and weaknesses involved in the use of the parametric associative CAD systems in the automotive design process. Furthermore this paper presents a prescriptive study in which the different phases and sub-phases of a newly-developed parametric associative approach are described, based on the identified factors and indicators in the previous steps (Descriptive Study I). By means of designing an inlet valve assembly the different phases of the developed approach are demonstrated (Prescriptive Study).

Keywords: parametric associative design, method development, method evaluation.
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1 INTRODUCTION

The development of modern computer-aided design (CAD) systems and the change from 2D design to parametric 3D modelling was one of the greatest challenges. Today, designers are confronted with modern CAD systems which allow them to connect their design knowledge and intention with the created CAD models and assemblies. But in a real industrial context the implementation and adoption of modern parametric CAD systems is not uncomplicated. Some of the reasons are that during the implementation important aspects like product, process and organisation of the company are not fully considered. The focus this of paper is the application of parametric and associative (PA) CAD systems in an industrial context especially in power train development in the automotive industry. According to [1] a parametric model is labeled by having certain attributes that makes modifications possible without deleting and recreating any of metrical components. For that reason variations are accomplished by modification the values of the parameters. Therefore, to accomplish modifications it is not necessary to delete and recreate the geometry new. Parametric systems solve constraints by applying sequentially assignment to model variables, where each assigned value is computed as a function of the previously assigned values [1]. Unlike procedural systems, the order of the assignment is flexible, determined by a constraint propagation algorithm". Related to design process associativity is the fix relationship and connection between geometrical entities and objects. These associative relationships include also the connection of 3D models and down stream process related elements (like calculation and manufacturing process). The parametrization of a 3D model (feature) implies the parametrization of derived information items of this 3D model (feature) that are a result of other applications (draft projections with dimensions or the numerical control program for the previous examples). By these means, any modification in a 3D model (feature) is automatically propagated to down-stream applications and connected geometries [2].

The motivation behind the paper is that the conversion of design intent and information from geometric modeling CAD Systems to "intelligent" modeling (where intelligent modeling means that the created CAD components contain rules and formulas which are embedded in the parametric and associative CAD parts and assemblies) is not easy [3]. Many designers have difficulties to identify possible methods of incorporating their knowledge or design intentions into such CAD systems, and in particular how to connect the "design-intelligence" which is appended to CAD models with the geometrical entities. Although very accomplished, many modern and capable CAD-systems are not able to capture the intention of the design experts totally and unmistakably. According to VDI 2209 [4] during the design process with a parametric CAD system there is a certain "thinking process" necessary which includes a modeling approach for creating the parametric models in a rigorous way. It has to be clarified how the identified and determined design parameters can be prepared and provided for the downstream processes like manufacturing, calculation or assembling [5]. Because of this a new method is needed which helps designers to handle this preliminary preparation and consideration phase during the work with PA systems and helps to create well-structured CAD models and assemblies [6]. This paper describes the stages of a research programme aiming to provide such an integrated approach, using the Blessing-Chakrabarti research methodology [7]. This methodology comprises four main phases, which correspond to the remaining sections of this paper: a research clarification stage through literature study; a descriptive study stage involving empirical analysis (in this case through questionnaire study and interviews with designers and investigation of existing parametric parts and CAD components in an industrial context); a prescriptive study phase involving exploration of new approaches which define different stages of how to work with PA CAD systems (the approach itself is called PARAMASS which means Parametric Associative Design) and finally a second descriptive study phase to evaluate the benefits of the new approach.

2 LITERATURE SURVEY

A number of authors have described methodological approaches and issues in design using PA CAD systems. Mendgen [8] presents an approach to parametric design based on the general methodical approach to design presented in VDI 2222, in particular the key phases of the design process. Mendgen identifies different steps of model creation which are necessary to achieve simple, well-defined and complete parametric models. These steps are: building the modelling elements and defining constraints between geometrical parts and assemblies; identifying modelling features and their structuring into components; identifying coupled and uncoupled relationships between features and other elements; classifying information at different levels of the assembly-part hierarchy; considering possible changes to models and careful naming of parts and features to allow identification of parts, properties and attributes. The approach is built into an assistance tool for parametric CAD systems based on a Tool Command Language (TCL), concentrating on geometrical constraint design and not considering downstream processes like finite element modelling (FEM) and computer-aided manufacture (CAM). Mendgen's approach is only defined at a high-level: logical or temporal relationships between the steps of model creation are not specified, and nor are detailed methods to represent the available parameters and associative geometrical elements. There is no systematic consideration of the design information inputs (i.e. design environment and product requirements) which are the basis of the parametric design and also design outputs which have to be delivered by the designer for downstream processes like manufacturing.

A further work related to the issues of PA model building is the work of Schenke, [9] the target of his approach was to solve the problem of different kinds of parameter uncertainty which arise in the different stages of the product development process. Depending on the product development process stages Schenke identified that the parameters in parametric modeling process can be different. That means that in the early stage of the product development the parameters are more undefined and "fuzzy". But in later stages of the product development process the parameters become more clear and defined. Schenke proposes that, related to parametric design, there are four kinds of parameter uncertainties, these are: data-, linguistic-, relation- and inconsistency-uncertainty. For solving and classifying the "fuzzy" parameters in the early stages of product development Schenke used the fuzzy set theory and developed an assistance system which can be applied to solve and determine the above mentioned types of parameters. The approach according to Schenke provides a solution of how to deal with parameter uncertainties in the parametric modelling process based on an assistant tool. Schenke used the approach according to VDI 2222 as the methodological basis to integrate his developed tool. Therefore the approach according to Schenke does not provide a method of how to work with PA systems in a systematically way. That means there the methodological aspects of how to identify and determine the important parameters and associative relationships during the parametric modeling process are not considered. Schenke only states that there is a hierarchical dependency between some parameters but a method of how to represent these kinds of hierarchical relations is not provided. Furthermore the relationships between the parameters and associative components which are important during the creation of a complex CAD part and assembly are not considered. Process related aspects which include downstream processes like FEM and CAM are also not considered.

The next relevant work is defined according to Forsen [10]. He considers workflow in parametric model creation, although at an abstract, theoretical level based on a transformation of systems theory to parametric design. His parametric design approach "PAKO" (PAKO is again from the German term PArametrische KOnstruktion) is a procedure based on three different phases. These phases are pre-CAD phase I, pre-CAD phase II and the CAD modelling phase itself. Furthermore these three phases are subdivided into different steps which are 1) separation of the system PAKO from the design environment, 2) formation of the system PAKO, 3) Formation of the system structure of PAKO, 4) Formation of the system hierarchy, 5) Formulation of the design strategy and 6) Formation of the system from concept to detail. The "PAKO" system according to Forsen is based on 25 different definitions which describe the relationship between the "PAKO" system itself and the environment. Furthermore these definitions which describe the characteristics of a system (for example that the PAKO system contains many CAD elements which have attributes and relations between each other) are more general statements on an abstract level and cannot be seen as an methodological approach. The approach which is defined by Forsen provides only some very abstract ideas of how to transfer the parametric modelling process into a system. Forsen points out that the working process with parametric and associative design systems requires a certain "thinking process" and therefore the modelling process should be planned. But there is no method provided how to create and plan this "thinking process". This aspect is very important and can be confirmed by the investigations which have been made by the author. The very abstract and theoretical consideration of the parametric design modelling according to Forsen does not provide a methodological approach to handle the important issues of how to deal with different kinds of parameters and associative relationships in design environment. The different approaches which have been presented and reviewed in this section of the work consider parametric design modeling from different aspects like functional, calculation, process and product planning. But in general a complete, integrated and generic approach of how to work with parametric associative CAD systems has not been presented.

The most important gaps and issues which are not addressed and considered in the reviewed literature are:

- An integrated approach of how to work with both the parametric and the associative aspects of CAD systems is not considered; furthermore an approach is required which can be used and extended to develop parts and assemblies.
- Many of the presented procedures do not consider the logical dependencies between the different procedure steps. That means that methodological methods are missing how to present the complex relationships between the components (relationships between parameters and associative relationships).

- Identification and determination of important parameters and associative relationships are only partly considered. That means approaches are missing of how to identify and determine the relevant parameters and associative relationships.
- Process and organizational aspects during PA design especially handling of associative relationships are not considered.

Figure 1 shows the different aspects of the reviewed approaches.

	Mendgen (1998)	Schenke (2001)	Forsen (2003)
CAD system independent aspects			
Consideration of preparation phase of design and modelling process (development of a modelling strategy)	-	-	○
Functional aspects			
Parameters: Identification, determination and representation of the parameters and their relationships to each other are considered	○	-	-
Associativity: Identification, determination and representation of the parameters and their relationships to each other are considered	-	-	○
Constraints: Consideration of constraints between parts and assembly features	●	●	-
Structural aspects of CAD modelling process			
Identification of P/A design information inputs and outputs	○	○	○
Process related aspects			
Consideration of downstream processes, CAM, CAE	-	-	-
Organisational aspects			
Simultaneous and current engineering	-	-	-

- **Not considered** ○ **partly considered** ● **fully considered**

Fig. 1: Different approaches related methods into parametric design.

For a better identification of the above mentioned problems and challenges the authors have undertaken a series of studies in an automotive industry environment. The main target of this descriptive phase was to address the important points which have been identified in the literature survey. Furthermore, the descriptive study should help to capture the experience of the parametric associative CAD users in an industrial context. The relevant design research methodology and the results of the descriptive phase will be presented in the next section.

3 RESULTS OF THE DESCRIPTIVE STUDY

The descriptive study was started with a questionnaire, the goal of which was to get more information about current knowledge of the designers and their work experience with parametric associative CAD systems in an industrial context. The aim of the descriptive study in the Blessing-Chakrabarti research methodology is to deepen the understanding of the research issues identified in the literature study. In the present work it was undertaken by questionnaire, interview and studies of existing parts in a large European automotive company and with engineers from its suppliers. The first part of the questionnaire contained general questions about design activities, experience, durability, and working skills with PA CAD systems. The second part contained questions related to functional and process aspects of PA design. The questions served to exemplify problems during the design process with PA systems and to address the issues which have been identified in the literature survey [11].

Environment	Automotive Industry and suppliers
Participants	153 power train engineering designers from automotive company and suppliers
Date Collection	Questionnaires
Time constraints	90 minutes for 26 questions
Team size	Groups of 10 people in different CAD design workshops
Duration	5 months (from creation phase to the analysis of the questionnaire)

Tab. 1: Basic conditions of the questionnaire.

Some of the key questions are listed above:

- The work with PA systems makes my activity as a designer considerably easier?
- Before to start to design with PA systems I think about the structure of my PA CAD models?
- At the work with PA systems I have an exactly defined approach (methodology)?
- At the work with PA systems I have to deal stronger with the CAD modelling process?
- I use the possibilities which are offered by PA CAD systems very well?
- I do not have enough time to be strongly engaged in the methodology of PA CAD models?
- During the modelling process I am able to find the right parameters and geometry in my complex CAD parts and assemblies?
- Changing of parameters and geometry of foreign CAD components can be done easily?
- With regard to foreign CAD components and assemblies it would be very helpful and desirable if there are more information about construction and structure of the PA CAD components. (Documentation of the construction).
- A description of construction and structure of PA CAD components and assemblies is very useful.
- With parametric associative systems geometrical changes can be done easier than with non-parametric systems.

The basic conditions of the descriptive studies are listed in Table1. The respondents of the questionnaire were designers whose work experience was on average over 12 years. But the parametric associative CAD system experience of the respondents was between one to five years. A key result of the questionnaire was confirmation that there is a significant need for a new approach to the use of PA CAD systems. 67% of the respondents were of the opinion that it is very important to concern themselves more strongly with the modeling process before starting to design with such systems and therefore they have to make some preparations of how to design and structure their PA parts and assemblies [10]. In addition 86% of the respondents think that there is a huge potential to improve the application of PA design. When setting the questionnaire the authors thought that a lot of methods would have the disadvantages of being time consuming and therefore not applicable in real design environment. But 52% of the respondents said that they are ready to invest time in a new method of PA design system. Furthermore 71% of the respondents denied having an exactly defined method and approach during their work with PA CAD systems and the remaining 29% who claimed to have a method said that many of the parts produced were poorly structured. We had hypothesized that failure to apply methods would be because of time pressures, but for only 19% of the designers it is quite difficult to spend time for application of particular methodologies. In addition 85% of the respondents also stated that during the preparation phase the right methods of how to identify, classify and determine the required parameters and associative relationships are missing. Another important question was the use of the full functionality offered by PA systems and only 14% of the respondents identified that they use the possibilities which such systems offer very well (for example, fully parameterized parts and associative connections) [10]. By means of this question it becomes very clear that there is also potential to improve the efficiency in the application of PA functionalities. In general because of the complexity of PA CAD systems there is a significant readiness of the designers to apply methods which help them to reduce the complexity and increase the transparency of the created CAD parts and assemblies - 76% of respondents would be interested in a method if it would help them during the work with PA design. The goal of further questions in the study was to analyse the PA modeling process used. Only 24% of the respondents indicated that they were able to find the right parameters and associative relationships in large and complex CAD parts and assemblies. This problem becomes bigger if they try to change parameters and geometry of “foreign” components (these are CAD parts which are designed by other designers or by supplier). Only 9 % of the designers are able to identify and determine the relevant information and they agreed that it is quite difficult to change CAD parts and assemblies created by other designers. The next important point was that 86% of the respondents agreed that in regard to such components and assemblies it would be very helpful and desirable if there is more information about the construction and structure of the PA part and assemblies. The designers appreciate the idea to have a description of the construction and structure of the CAD parts. A further important aspect was the use of associative connections between parts and assemblies. This aspect has shown the greatest gaps and weaknesses. Only 19% of the respondents agreed with the question “I use different kinds of linkages offered by PA systems in my parts and assemblies (linked drawings, geometry elements, FEM etc)". This suggests that designers have not the right methods to handle associative connections. Furthermore because of the lack of a method most of the designers have had bad experience with such associative relationships. In general the results of the questionnaire confirm the issues which have been identified during the literature survey. More extensive details are given in [10]. The questionnaire study was followed up with interviews which have been done with eleven experienced CAD coaches and designers. The most important aspects and results of the interviews with CAD experts and coaches can be summarized as follows [11]:

- During the work with PA systems, designers have difficulties to identify, determine and represent relevant parameters and associative relationships;
- The created associative relationships are not well thought out and elaborated. Designers create many associative relationships between the geometrical entities without being aware of the consequences;
- A preliminary consideration and preparation of the created parameters and associative relationships would be a great asset for the designer. This aspect improves the identification, determination and representation of the created associative relationships;
- Designers are confronted with problems which are not related to the product but are rather related to the logical aspect (relationships between parameters and associative geometries);
- Parametric associative CAD parts and assemblies modeled by other designers are often not well structured and therefore it is quite difficult to change them or to find relevant design information.

The results of the interviews showed the same important aspects that have been identified during the analysis of the questionnaire. The next section will explain the developed approach based on the findings in the literature survey and descriptive study.

4 APPROACH OF AN INTEGRATED APPROACH FOR PARAMETRIC ASSOCIATIVE CAD SYSTEMS

Based on the input from the literature and descriptive studies, a novel approach to the methodical application of PA CAD systems has been developed. The graphical representation of the developed approach can be taken from Figure 2. Now the different phases of the developed approach will be presented.

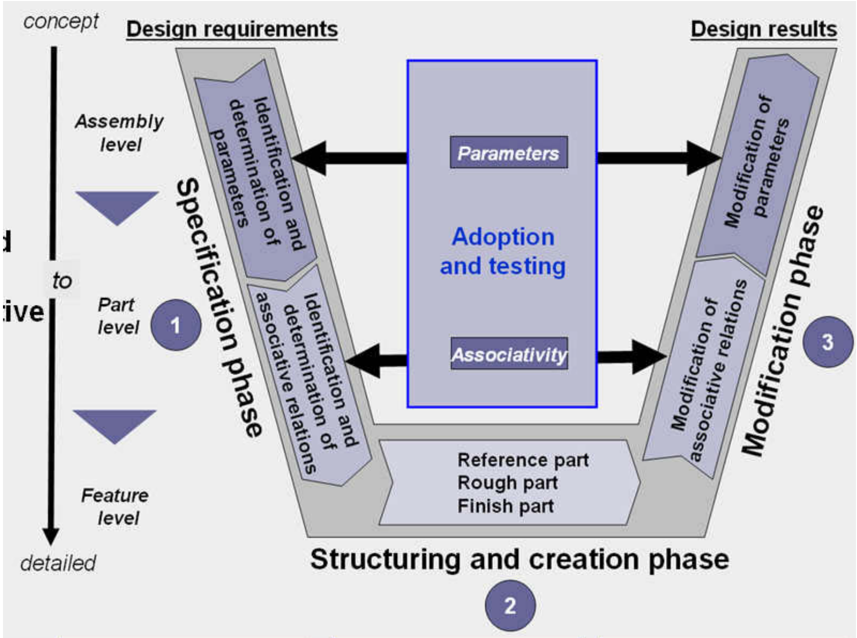


Fig 2: Generic integrated approach of parametric associative CAD systems.

It is based on three different main phases which comprise the top level of the approach [12].

1. Specification phase for PA CAD parts and assemblies
    1.1 Identification and determination of parameters.
    1.2 Identification and determination of associative relationships.
2 Structuring and creation phase of PA CAD design.
    2.1 Structuring and creation of parameters and associative relationships on a part structure level.
    2.2 Structuring and creation of machined parts on associative assembly structure.
3 Modification phase of the parametric associative CAD design.
    3.1 Modification of parameters and associative relationships
    3.2 Modification of the created structure

The stages of the approach to PA CAD are shown in Figure 2 and are based on the V-model approach to systems development. The V-model is a graphical representation of the systems development lifecycle [13]. The V-model is a guide for the basic procedure based on system engineering process (originally from software engineering) and is adapted to the requirements of mechatronics. It describes the logical sequence of important sub steps in the development of systems. Furthermore the V-model describes a generic procedure for designing systems, which is to be given a more distinct form from case to case [13]. The left side of the V-model represents the decomposition of requirements, and creation of system specifications. The right side of the V-model represents integration and modification of parts and their verification. The V-model deploys a well-structured method in which each phase can be implemented by the detailed documentation of the previous phase. In V-model representations, time and maturity move from left to right. Iteration is essential in system development, and all iteration is done vertically. The left leg of-V-model investigations center around what concept is best and what architecture is best for that concept. The relevant factors of the V-model in describing these aspects are [13]:

- The V-model is used in different industries, including automotive and aerospace. Furthermore the V-model is a very well known approach which has been used and applied by the designers in their product development process.
- The V-model approach consider the concept level of the product development process
- The V-model is divided in subsystem/Component level, which produces first a set of subsystem and component product performance descriptions, then a set of corresponding detailed descriptions of the products' characteristics, essential for their production is also considered.

By means of the V-model it was possible to integrate the different level of the product development process and structure from concept to the detailed phase. Furthermore the different level of the system and components (assembly of part level) are integrated inside the developed approach. This was an aspect which was not considered during the method development process by the author and after the first trial of the developed method this was one of the important aspects which has been identified and required by the designers during the method application. Based on the input from the literature and descriptive studies, a novel approach to the methodical application of The descriptive study was started with a questionnaire, the goal of which was to get more information about current knowledge of the designers and their work experience with parametric associative CAD systems in an industrial context. The aim of the descriptive study in the Blessing-Chakrabarti research methodology is to deepen the understanding of the research issues identified in the literature study.

4.1 Specification Phase for PA CAD Parts and Assemblies

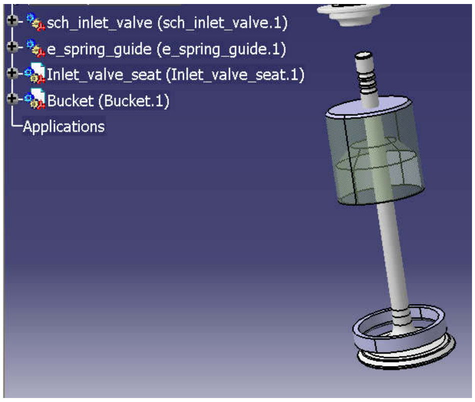
The method approaches according to Pahl and Beitz [14] and VDI 2222 [15] contain a specification or planning phase which is one of the important aspects of the design methods in widespread use. The results of specification phase are to gain information which can be converted into useful and essential design knowledge. The developed specification phase of the approach is divided into two different sub-steps. These are identification and determination of parameters and associative relationships. The selected approach to capture the gained "knowledge" and information during the specification phase for PA design information is a checklist which is 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.

4.1.1 Identification and Determination of Parameters

The final results of the questionnaire showed that 76% of the respondents confirmed that during the modelling process they were not able to find the right parameters in large and complex CAD parts and assemblies. This problem becomes bigger if the designers need to change the parameters and geometry of "foreign" components and assemblies (CAD parts and assemblies which are created by other designers e.g. by suppliers). The results of the descriptive study (results of the literature survey and carried out questionnaire) demonstrate that the relevant parameters during the design process with PA systems can be classified into three different categories:

- <u>Geometry parameters:</u> 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 [16].
- <u>Physical parameters:</u> 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 [16].
- <u>Process parameters:</u> These are parameters which define the selected process of the selected technology. Process parameters can be for example machining-processing data or heat treatment requirements (calculation and manufacturing parameters) [16].

The structure of an inlet valve assembly contains 4 different CAD models which are the inlet valve itself, the spring carrier, the valve seat and the bucket tappet (Figure 3). 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 an inlet valve the parameters which describe the geometrical artifact are valve stem diameter, valve stem cotter, throat valve seat, total valve seat face thickness, height of valve seat, height of valve seat face, head diameter, throat angle, valve seat angle, total length and grinding length of the valve. Furthermore the above mentioned geometrical parameters can vary for different engine types with different cylinder bore diameters. In this case the PSM approach can be used to identify, determine and document this kind of geometrical relationships and dependencies. In later steps of the CAD modelling process this knowledge can be implemented in the CAD model and can be captured from the PSM structure. For a better capturing, documentation 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 3). The framework of the PSM is based on the logic and structure of the Design Structure Matrix (DSM) approach [17].



Category	Geometry parameter									Physical Parameter			Process Parameter		
Organisation	CAD									CAE			CAM		
Parameter name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Valve head															
2. Valve radius	X														
3. Valve angle	X														
4. Valve stem diameter															
5 Valve height															
6. Valve neck radius															
7. Valve stem				X		X									
8. Throat angle	X														
9. Valve height	X														
10. Surface											X				
11. Roughness											X				
12. Material											X				
13. Valve head Surface	X													X	
14. Valve stem face				X			X							X	
15. Clearance between valve														X	

Fig. 3: The CAD model of a inlet valve assembly (left) and the PSM of the inlet valve (right).

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, and by means of this abstraction it is possible to find higher level interrelationships that are more generic and comprehensive. Abstraction in this way supports systematic thinking. In the current work, 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. In a PSM the "X" in a cell is used to indicate the coupling and relationships between the different kinds of parameters. 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 [17] in three different organizational categories which are CAD, Computer Aided Engineering (CAE) and Computer Aided Manufacturing (CAM). The clustering processes are generated automatically by defined procedure and macros (in Visual Basic Languages) in PARAMASS tool. Furthermore this tool was developed to support designers during the creation and generation of the PSM. It helped to collect and document the created PSM and the required information. 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. 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. In case of the inlet valve the PSM approach can also be used to develop a catalogue of modular valves for different engine types and families.

4.1.2 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. 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 modelling" which describe the associative relationships between the geometrical entities [18]. The characteristic of adapter/skeleton parts and assemblies are [18]: a) it models contain geometrical entities and parameters (i.e. points, lines, shapes and solids); b) are models characterized by an exactly defined geometrical interface; c) use linear associative relations; d) are hierarchically ordered; e) can be defined by simultaneous or concurrent engineering teams; f) can also be considered as an interface to the downstream processes (CAM, CAE). Adapter and skeleton models simplify design creation and visualization, help to manage relationships and to provide control over external references. The act of creating associative relationships between the geometrical entities is also called "referencing". Therefore the models which contain the basic associative elements are called the "Reference models", and will be used here 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 (Figure 4).

	Part name	1	2	3	4	5	6	7	8	9	10	11	12
1	Intake valve								X			X	X
2	Camshaft			X									
3	Tappet												
4	Valve spring retainer	X		X									
5	Valve spring	X					X		X				
6	Valve stem seal	X											
7	Valve guide	X							X				
8	Cylinder head												
9	Spark plug								X			X	
10	Valve seat	X							X				
11	Combustion chamber								X				X
12	Piston								X				

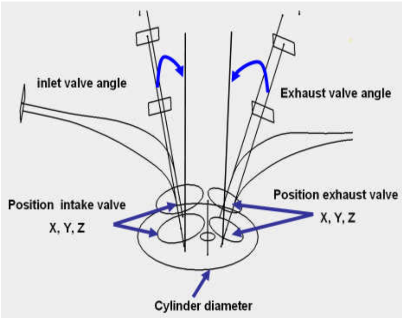


Fig. 4: ASM approach of the inlet valve (left) and the adapter/skeleton model (right).

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 [13]. A geometrical interface analysis is now used to help to identify the important associative relationships for the inlet valve. For a better capturing and collecting of the above mentioned associative connections a checklist which is based on an Associative Structure Matrix (ASM) has been created. The ASM approach contains the associative relationships between the geometrical entities. The framework of the ASM is again based on the logic and structure of the DSM [12]. 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.

4.2 Structuring and Creation Phase of the Parameters and Associative Relationships

The structuring and creation phases help to order 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 of the CAD parts and assemblies. The structuring approaches of the developed CAD models and assemblies can be “top-down” or “bottom-up”. A top-down design environment supports transitions from high-level, conceptual assembly models stressing the function of the assembly to detailed models of the individual components. The “bottom-up“ approach starts with designing a single CAD part on the low level of the product structure [19]. 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. The approach selected in the present work is based on the “top-down” approach. That means that the structures which are predefined are created and given top-down [19].

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. The pre-defined structures of the approach are a) Parametric Associative Assembly Structure (PAAS) and b) Parametric Associative Part Structure (PAPS) [12]. The PAAS is based on associative relationships between different CAD parts which represent the hierarchical structure of the designed parts and assemblies (Figure 5). The PAAS is hierarchically ordered and contains three different models 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 identify the different parts which are created in PAAS so that a concurrent and simultaneous engineering environment can be enabled [12]. 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. 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 basic-element of the CAD component (Figure 5). These basic-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.) [12].

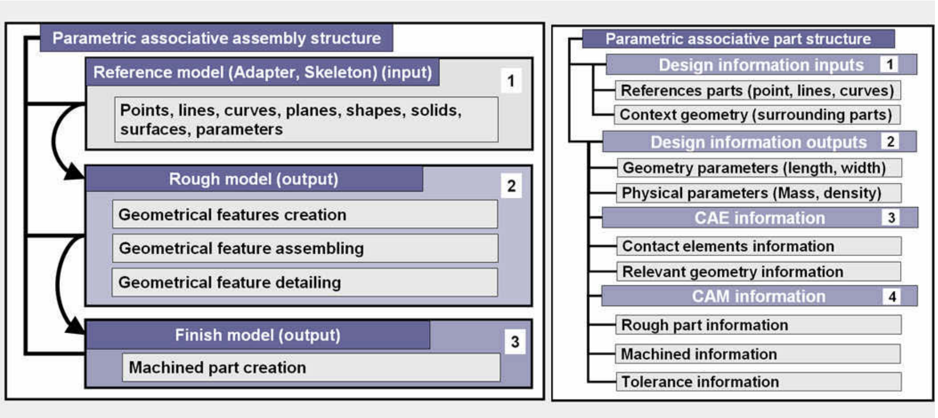


Fig. 5: Structuring of design information inputs and outputs at part and assembly level.

The next predefined structure is the PAPS which are divided in 4 different parts. These parts should help to structure the identified parameters which are necessary for the downstream 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 basic 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. The third and the fourth part of the PAPS are created to enable the exchange of information which is necessary for the downstream processes. In this case these two areas are CAE engineering and CAM engineering process partners. Based on the reference model and by means of associative connections the step 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 inlet valve which is the difference between the rough part and the machined part elements (i.e. turning and fine grinding) [12].

4.3 Modification Phase of the Parametric Associative CAD Design

The last phase of the presented approach involves the possible modification of the created parameters and associative relationships and helps to test and evaluate these. The most important point during the modification phase is to check a) the consistency of the created parameters to ensure that they can be changed and the CAD parts and assemblies can be regenerated without failures and b) the consistency of the created relationships between the geometrical entities and objects to ensure that in case of geometrical changes the associative relationships still work. By means of the PSM and ASM approach it was possible to define a method to identify, determine and document the relevant parameters and associative relationships between the geometrical entities. The predefined structure layout of the created PA components increases design transparency and reusability, standardizes the design structures, defines a hierarchical order of the different design information inputs and outputs and integrates clustered and classified parameters and associative relationships in the CAD parts and assemblies. The author was able to observe that during the application of the predefined PAAP and PAPS designers had advantages related to the reusability of the created PA parts and assemblies.

5 CONCLUSION

At first the following paper demonstrated the results of a literature survey on the field of parametric associative CAD design systems. It becomes very clear that during the design process with parametric and associative CAD systems there are methods and approaches necessary of how to identify, document and determine the different kinds of parameters and associative relationships which are necessary during the design process with this kinds of systems in the design process. The next section presented a prescriptive study in which the different phases and sub-phases of a newly-developed parametric associative approach (PARAMASS) was described, based on the identified factors and indicators in the previous section. Furthermore by means of Parameter Structure Matrix (PSM) and Associative Structure Matrix (ASM) it was possible to identify, document and determine the different kinds of parameters and their relationships with each other. By means of designing an inlet valve assembly the different phases of the developed approach were demonstrated and presented.

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