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# ACTION RESEARCH INTO THE USE OF PARAMETRIC ASSOCIATIVE CAD SYSTEMS IN AN INDUSTRIAL CONTEXT

**Vahid Salehi, Chris McMahon**
University of Bath, Bath, UK

## ABSTRACT
The automotive engineering process is characterized by a long and complex design activity which starts with requirements formulation and the 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 best to use such systems. This paper reports the first stages from a research programme into the application of parametric associative CAD systems adopting the design research methodology (DRM) according to Blessing. The focus of this paper is to present the results of the descriptive study which has been accomplished to identify the challenges, problems and weaknesses involved in the use of the systems in the automotive design process. After a short introduction the result of a literature survey on the field of parametric associative CAD design systems is presented, including an evaluation of reviewed papers and research from different aspects. The review is followed by presentation of the results of a questionnaire and interview study of engineers working in the automotive industry. This study demonstrates that engineers have significant difficulty in identifying and structuring the parameters and associative relationships used in parametric associative CAD, especially in distributed design tasks. The review and the empirical study demonstrate the necessity of generic integrated approaches to working with parametric associative CAD systems. The paper concludes with identification of the most important issues which should be considered in development of such generic integrated approaches.

*Keywords: parametric associative design, method development, CAD systems, Action research, parametric design*

## 1 INTRODUCTION
The current situation in the automotive industry is characterized by new requirements of the global market with huge international competition. The conditions which control today's automotive market lead to the following goals: highest possible quality, quick response to the demands of the market and reduction of costs. In addition to these three goals, automotive companies need new and innovative products to set themselves apart from international competitors. In order to fulfill these requirements, automotive manufacturers try to create new and efficient processes based on virtual engineering systems. One of the perspectives for reducing cost and time of product development is to create efficient virtual product development (VPD) processes. For realizing these needs there is a huge demand for capable Computer-Aided Design (CAD) tools like parametric associative CAD systems. These kinds of systems are able to record design steps and relationships allowing reuse of designs, potentially allowing a faster and more powerful virtual development process.
A parametric associative (PA) model is a computer-based geometrical depiction of a design that has certain characteristics that can vary: the characteristics are controlled by non-geometrical components that are called parameters. The characteristics and attributes of the PA model will be dependent on the

value of the parameters [1]. 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 [1]. 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 [1]. 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 [1].

Normally in parametric CAD, designers are able to describe a geometric feature with several parameters. Moreover the designer is able to modify the geometry by changing the geometrical parameter values instead of deleting geometric entities. Associative environments enable CAD designers to maintain the relationships between geometrical objects, features and diverse design process steps (for instance linkage between CAD model and FEM model or CAD drawing) [2]. Designers are able to create relationships between systems and components. Significant assets of these systems are the ability to keep all the sequential steps and operations which describe the part or the product model. In technical terms this point is also called the storing of design creation history. However, 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. Many designers find it very difficult 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 [3] 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. Furthermore there is some preparatory work necessary which includes the definition and determination of the design, manufacturing, calculation, process and organizational aspects like geometrical, physical and process parameters of the product [3]. Furthermore it has to be clarified how the identified and determined design parameters can be prepared and provided for the downstream processes. Because of this situation a new generic integrated 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. This paper describes the first stages of a research programme aiming to provide such a generic integrated approach. In particular, it will report on the first descriptive study phase of the programme, which is adopting the Blessing-Chakrabarti research methodology [4]. This phase has included a literature review aimed at identifying the research gap in methodological approaches to parametric-associative systems, and has followed this with a detailed study of designers' needs, carried out by questionnaire, and interview. These aspects are reported in the remaining sections of this paper.

## 2 LITERATURE SURVEY

In the search of the literature about methods and approaches to PA design it is very important to distinguish between research papers, theses and commercial publications. Commercial publications describe only the functionality of different parametric systems, for instance Pro/Engineer or Unigraphics. Most of these publications do not describe a general methodology for how to use the systems but define only specific capabilities and applications of such systems. They can be seen as a description of how to use certain functionalities offered by specific CAD systems. Furthermore, for many designers, it is difficult to reflect the described approaches in their daily design work. They know how the software may be operated, but need advice about the way it should be used.

In this section previous research on parametric and associative design approaches will be summarized. The scientific work related to parametric and associative CAD modeling is multifaceted and considers parametric design from many different views and aspects. Vajna [5] analysed existing parametric modules and functions for the development of general remarks on parameterization in the product

development process. This includes amongst other aspects the creation of part families and the identification of form elements inside part families. Furthermore he recommended [5] the definition of relation structures for the existing constraints and building documentation of the parametric CAD model. But this approach does not consider the methodological aspects which are necessary to work with parametric associative CAD systems in the product development process to create such structures and documentation. In other work, Gausemaier [6] presents an application tool to define the semantics of parametric design elements. He [6] identified that it is very important to work out a guideline which describes the semantic nature of parametric CAD models, and describes how the constraints of the CAD models may be coupled to their semantic elements [6]. The approach according to Grabowski [7] includes the creation of flexible parametric design elements at an assembly level. That means the focus of his work is to structure the relations between the different design dimensions especially in constraint modeling. The structural relationships describe the geometrical constraints like parallelism and coincidence between the geometrical elements. It does not consider the fixed associative relationships between the geometrical entities like fix associative connections between 3D elements and objects (associative relationships between 3D model and 2D drawings). In this case the methodological aspect of PA design is not considered – the designer is informed about parameters in models and the relationships that are needed between model elements but not how, systematically, these parameters and relationships may be created. In other words the research did not consider the specific steps and procedures that need to be adopted by designers in order to create suitable models and relationships.
Other research in parametric CAD modeling has considered the functional aspect of modeling. For example [8], [9], [10] and [11] developed approaches which include only the adoption of functional aspects to parametric CAD models. Krause [12] developed an approach to exchange parametric information based on an implicit feature-oriented product description. The focus of his work was to create architectures of how to exchange parametric elements which are used to describe parametric models. By means of such architectures the exchange of geometrical information between different parametric CAD systems can be enabled. The basis of this approach is a neutral data format. Furthermore there is a generic description and representation of the parametric CAD models available. In all of the reported approaches, however, the methodological aspect of parametric CAD modeling is insufficiently developed.

### 2.1 Associative Models

A number of authors have considered the up-stream and down-stream connection of CAD models to requirements planning, analysis and manufacturing. In requirements planning, Weck [13] developed an approach of how to connect technical product requirements with parametric CAD models. Furthermore the target of his work is the early identification of problems between technical product requirements and the current parametric CAD models. In a downstream connection, Meerkamm [14] developed an approach to integrate the calculation and dimensioning process of parametric parts and assemblies in the product development process. Ledermann [15] presented a method to connect parametric CAD models in the aerospace industry to FEM models. The target of this approach is to calculate and assess different instances of a given aircraft structure in an automated way by means of a PA part library. Furthermore, aeroelastic optimization can be performed by using this library to couple the CFD Software FLUENT with the CSM code MSC.Nastran. Further works which are related to integration of calculation and FEM in design processes are written by [16], [17], [18]. The target of these methods is to create an interface between the available FEM tools (i.e. ANSYS, FLUENT etc.) and parametric CAD models. Most of these approaches are based on neutral data formats like STEP, VDAFS, DXF or XML languages. The disadvantage of the presented approaches is the interruption between the native parametric CAD models and the FEM models therefore the focus of this work is the transformation of CAD information data from certain specific CAD systems to the FEM tools. Modern parametric associative systems like Pro/Engineer and CATIA V5 offer integrated FEM tools which enable a direct association and connection of native CAD data with FEM models. Furthermore this works does not consider the methodological aspect of how to integrate the identified and determined process and physical parameters in the design workflows and activities.
In manufacturing, Ma and Tong [19] used associative features to design parts of a plastic injection mould and provide manufacturing information. The target of their work was to use associative features to design a cooling channel based on a fully parametric CAD model. As a result they developed a tool

which is able to generate cooling channels fully automatically. Bossmann [20] developed an approach to connect feature based product and process planning in product development process. The work is based on skeleton technology (where 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 [21]) and considers only the product planning aspects. Furthermore, Bossmann has analyzed the product planning activities which are necessary to manufacture a parametric product.

While there have been extensive studies of the application of associative CAD models throughout the product introduction process (the work presented is by no means a complete list), in all the work described, the authors say what are the necessary information models and structures to achieve a particular result, but they do not provide detail of the procedures and methods needed to create such models and structures in a systematic manner - in other words they neglect the methodological aspect. We turn now to work that does attempt to address this issue.

## 2.2 Methodological Approaches

The approach developed by Mendgen [22] is based on especially defined rules. These basic rules define that parametric CAD models should be a) well defined b) simple and c) complete. He divided the parametric design process in six phases which include: (a) Building the modeling elements and their constraints to each other; (b) Structuring in single components; (c) Coupling and uncoupling; (d) Classification in detailed modeling; (e) Thinking about possible changes; and (f) Clean modeling.. The main focus of Mendgen's approach, however, is the application of a method in geometrical constraint design (parallelism, tangency, coincidence etc.) without any associative relationships to the design context (connections to the surrounding geometry) and environment.

Further research related to the parametric design method is defined by Schenke [23]. The main target of his work is to solve the different kinds of parameter uncertainty which arise in the different stages of the product development process. At the early stage of product development, parameters are not well defined, these kinds of parameters are defined as "unscharfe" parameters (the term "unscharf" is German and means fuzzy, unclear or cloudy). However, in later product development phases the parameter (information content) gets more clear and detailed. Schenke describe these parameters as "scharfe" parameters (the term "scharf" is German and means clear or well defined). In addition related to parametric design there are four kinds of uncertainties, these are: data-, linguistic-, relation- and inconsistency-uncertainty. For solving and classifying "unscharfe" parameter in early stage of product development Schenke used fuzzy set theory and developed the assistance system "PARAKON" (from the German term PARAmetrische KONstruktion, in English parametric design). The system "PARAKON" is based on different modules. However, the tool "PARAKON" does not define a method of how to work with parametric systems. It is only a tool to collect unconnected information during the geometry creation. The biggest disadvantage of the procedure defined by Schenke is that this approach can not be seen as a new "method" because firstly it uses an existing method (VDI 2222) and secondly the main part of the work contains the solution approach of how to deal with the uncertainty of the parameters during the design process.

The next relevant work is by Forsen [24]. It describes the parametric design approach "PAKO" (PAKO is again from the German term PArametrische KOnstruktion). The focus of this approach is to transform parametric design to a technical system and to describe the properties of this technical system. One of the disadvantages of his approach is that there is only a transformation of systems theory to parametric design. One of the aspects pointed out by [24] is that the working process with parametric and associative design systems requires a certain "thinking process" and therefore the modeling process should be planned. The PAKO approach comprises three different phases which are subdivided into six steps. The phases are pre-CAD phase I, pre-CAD phase II and the CAD modeling phase itself. The subdivided steps are 1) separation of the system PAKO from the design environment, 2) formation of the system PAKO, 3) formation of the 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. Furthermore the "PAKO" system is based on 25 different definitions which describe the relationship between the "PAKO" system and its 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:

1. A generic integrated approach of how to work with both parametric and associative aspect of CAD systems is not considered;
2. Approaches which are presented in the viewed papers are component oriented and therefore not necessarily transferable to other CAD parts and assemblies (application development). The term component oriented means that the developed approaches are application specific and describe only how to design a certain component for example to design an automotive door but explanations on how to extend the method to other components are not given;
3. Many of the presented procedures do not consider the logical dependencies between the different procedure steps. That means that the created result of the different steps of the procedure does not deliver the inputs to the next steps;
4. The preliminary thinking process which is necessary to have a clear understanding of how to design PA CAD parts and assemblies is only partly considered;
5. Identification and determination of important parameters and associative relationships are partly considered;
6. Process and organizational aspects during PA design especially handling of associative relationships are not considered.

The following open questions are therefore identified:

- How can relevant design parameters in an engineering design process be identified and determined?
- How can dependencies between the parameters and associative relationships in the engineering (design) process be represented, well structured and created?
- How should the structure of PA CAD parts and assemblies be created for a more efficient and better representation of the relevant design information inputs and outputs?

For a better identification of the above mentioned problems and challenges the authors have undertaken a series of studies in an automotive industry environment, including questionnaires, interviews and studies of existing parts. 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 DESIGN RESEARCH METHODOLOGY AND INITIAL RESULTS

One of the most important points of all scientific work is the explanation of the research methodology which gives an overview of the way the research has been undertaken. The research reported here uses the research methodology according to Blessing [4]. The reason is that this approach allows researchers to generate a research process with consideration of very important aspects like data sources, documentation of research results, definition of measurable criteria and success, definition of a reference model ("as is" process) and the subsequent comparison with the "to be" process. This work is also based on an inductive-empiric approach which contains analyses, case studies and the questioning of industrial experts. The design research methodology (DRM) according to Blessing [4] contains four different stages. These are (a) criteria; (b) descriptive study I, (c) prescriptive study and (d) descriptive study II. The focus of the present paper is to explain only the relevant criteria and the results of the descriptive study I in a very detailed way. The definition and results of the prescriptive study and descriptive study II will be presented in later papers.

### 3.1 Definition of the criteria

The first step of DRM according to Blessing [4] is to define the criteria, the basic goals and purpose of the scientific work. For a scientific research area, such as design, which intends to improve a situation like design tasks or processes, establishing success criteria is very important. The main goal is to reduce the negative factors and support the positive ones influencing the performance of the design process, but measurable success criteria should be defined as the basis for evaluating the success of new design knowledge [4]. The main tasks of these criteria are: a) the identification of the goal that the research work is expected to reach and the focus of the research project; b) to focus Descriptive Study

I on finding the factors that contribute to success; c) to enable evaluation of the developed support (Descriptive Study II).

To make the results and benefits of the new developed approach in this work measurable the author defines quantitative and qualitative criteria [25]. Quantitative criteria are measurable, for instance time, the sequence of method, design data quality and costs. These are based on application of defined scenarios (use cases) which describe a certain design task and the measurement of the steps performed during the application of the new method [25]. For the present work the measurement of criteria like method time, number of method steps and measures of CAD model quality will be accomplished by studying different use cases. Qualitative criteria like usability, designer satisfaction and motivation are not measurable easily, but can be investigated by empirical studies, for example by interviewing designers about the generic integrated approach before and after the application of the method [25].

## 3.2 Descriptive study I

This section describes the main characteristics of empirical-descriptive methodologies in design research and shows the significant attributes. The descriptive study I is one of the most complex parts in the Design Research Methodology according to Blessing. Therefore, this section of the work will handle and explain the different methods and possibilities of descriptive studies (for instance observations, questionnaires, interviews, and experimental methods). A very important way of investigating design methodology is empirical research, which can be real or experimental [26]. One of the characteristics of descriptive methodologies is that they do not define a certain hypothesis about the so-called “right” procedure [27]. Descriptive methods analyse and describe the current situation [27]. In this part of the work the author has analysed some results of descriptive methodology in the design process.

According to Baya [27] descriptive studies offer a characterization, description and understanding of what happens during the design process. These studies may be based on a profound analysis of Action Research, in which the researcher is present in the studied activities either in a passive way as simple observer or in an active way as a team member sometimes also described as Participation Action Research [27]. The present work adopted an Action Research approach in a CAD design environment where the researcher accompanied and worked with designers during their design activities. Some advantages of action research are [28]:

a) A minimum risk of loss of valuable information/data due to forgetfulness or incorrect reconstruction. When reconstruction of past events is made, e.g. in an interview, there are risks of misunderstandings. The researcher has no opportunity to consider the circumstances outside or inside the studied process that may have influenced the result;
b) First hand information eliminates the influence from other people’s understanding of the situation and their ways of expressing it.
c) Opportunities exist to rapidly make corrections in interview documents or to clear out misunderstandings between the questioners and the respondents.

In the present work, the Action Research being undertaken is supported by questionnaire and interview study of the design teams involved, as described in the next section.

### *3.2.1 Questionnaire Study*

The goal of this questionnaire was to get more information about current knowledge of the designers and their work experience with parametric associative CAD systems. The descriptive phase of the research has been started with a questionnaire. A questionnaire is a research instrument consisting of a series of questions and other prompts for the purpose of gathering information from respondents [29]. The design of a questionnaire can be divided into three sub-elements: a) Clarification of questions that can be asked b) Selection of question type for each question and specification of the wording c) Design of the question sequence and overall questionnaire layout. Questions can be established through the process of both studying the literature and one’s own reflection, and can be of two types, either open or closed with single or multiple responses, ranking, and rating [28]. An open question is one which doesn’t provide any standard answers to choose from. A closed question is one which provides the response categories from which the respondent just chooses one.

The questionnaire in the present work is a mixture of closed and open questions, divided into two parts. The first part contains general questions about design activity, experience, durability, and working skills with parametric associative CAD systems. The second part contains questions related to

functional and process aspects of PA design. The questions serve to exemplify problems during the design process with parametric associative systems and address the issues which have been identified in the literature survey. Furthermore the main goal of the questionnaire is to get a better understanding of possible challenges and problems during the work with PA systems. The design of the questionnaire is based on the Goal Question Metric (GQM) approach [30]. The GQM is a top-down approach to create a goal-driven measurement system, in which the researcher starts to define goals, poses questions to tackle the research goals, and identifies metrics that present answers to the questions [30].
The **Goals** at the top of the GQM tree are the measurement goals that are the outcome of step 1 of the GQM process. They are quantified by their linkage to questions and metrics as noted in the mapping, and include four aspects to describe what the measurement should achieve:
*Object:* The product or process under study; e.g. researching of parametric associative CAD design environment in industrial context;
*Purpose:* Motivation behind the goal (why); e.g. better understanding of the design process with PA CAD systems and the identification of improvement potential (identification and determination of relevant parameters and associative relationships, research of the structural representation of parameters and associative design information);
*Viewpoint:* Perspective of the goal (who's viewpoint); e.g. CAD designer; CAD trainer
*Environment:* Context or scope of the measurement program; e.g. industrial context, design department
**Questions** in the GCM approach help identify interpretations of the goal that may exist among the stakeholders as well as constraints imposed by the environment. Typically, at the project level, conceptual measurement goals are identified relating to product quality, process, resources, or the environment [30]. The questions are about the identification and determination of the relevant design parameters and associative information during the design process.
Finally, **Metrics** are about examining the questions which could be answered, moving from the qualitative to the quantitative level. Once goals are refined into a list of questions (GQM process step 2), metrics need to be defined that provide all the quantitative information to answer the questions.
The questionnaire was carried out in an automotive company and the respondents were designers in power-train development. As mentioned before the questionnaire in the present work is a mixture of closed and open questions, divided into two parts. The first part contains general questions about design activity, experience, durability, and working skills with parametric associative CAD systems. The second part contains questions related to functional and process aspects of PA design. The basic conditions of descriptive studies are listed in Table 1:

*Table 1. Basic conditions of the questionnaire*

| | |
|---|---|
| Environment | Automotive Industry and suppliers |
| Participants | 153 power train engineering designers from automotive company and suppliers |
| Collection methods | Questionnaires |
| Time constraints | 90 minutes for 26 questions |
| Team size | Groups of 10 people in different CAD design workshops |
| Number of cases | 153 questionnaires |
| Total duration | 5 Months (from creation phase to the analysis of the questionnaire) |
| Role of researcher | Accompanying the designers (explaining and answering questions) |

The goals of the questionnaire were to research a) the CAD knowledge and experience of the designers; b) the work experience of the designers; c) the understanding of the respondents related to parametric associative CAD systems; d) the weaknesses and problems during the design process with parametric associative CAD systems; e) the structural aspects of the design information inputs and outputs. 26 questions were created. The respondents of the questionnaire were designers whose work experience was in 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 generic integrated approach of parametric associative 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 parametric associative CAD systems and therefore they have to make some preparations of how to design and structure their PA parts and assemblies. Furthermore this aspect confirms the issues number 4 which has been identified in the literature survey (section 2.2). 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.

Furthermore 71% of the respondents denied having an exactly defined method and approach during their work with parametric associative CAD systems and the remaining 29% who claimed to have a method said that many of the parts produced were poorly structured. The main goal of this question was to identify the necessity of a generic integrated approach with PA systems and to confirm the issues number 1 and 2 (missing generic method) in section 2.2. We had hypothesized that failure to apply methods would be because of time pressures, but only 19% of the designers responded it is quite difficult to spend time for application of particular methodologies for this reason, but these answered that they would apply a certain methodology if they would have more time. 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). By means of this question it becomes very clear that there are also potentials to improve the efficiency in the application of PA functionalities. In addition 86% of the respondents think that there is a huge potential to improve the application of PA design. A lot of methods have the disadvantages to be 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. A further 24% would be interested in a method if it would help them during the work with PA design. In general because of the complexity of parametric and associative 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.

The goal of further questions was to analyse the PA modeling process used. The author asked if designers were able to identify and determine the important parameters or associative geometries. 76% of the respondents indicated that 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 they try 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 quite difficult to change CAD parts and assemblies created by other designer. The before defined aspects confirm the issue number 5 which has been identified during the literature survey in section 2.2. 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 parametric associative CAD parts and assemblies.

The next important aspect was the use of associative connections between parts and assemblies (see figure 1). This aspect has shown the greatest gaps and weaknesses. Only 19% of the respondents agree with the question "I use different kinds of linkages offered by PA systems in my parts and assemblies (linked drawings, geometry elements, FEM etc)". The reason is that designers have not the right methods to handle associative connections. Furthermore because of the lack of a general integrated method most of them have had bad experience with such associative relationships. This aspect confirms the issues number 4 and 6 which has been identified in the literature survey (section 2.2). Figure 1 shows some of the failure which can be made during the design process with parametric associative CAD systems.

In general the results of the questionnaire confirm the issues which have been identified during the literature survey. Figure 2 shows the important results of the questionnaire, where each axis is the proportion of respondents agreeing with the statement or applying the approach.

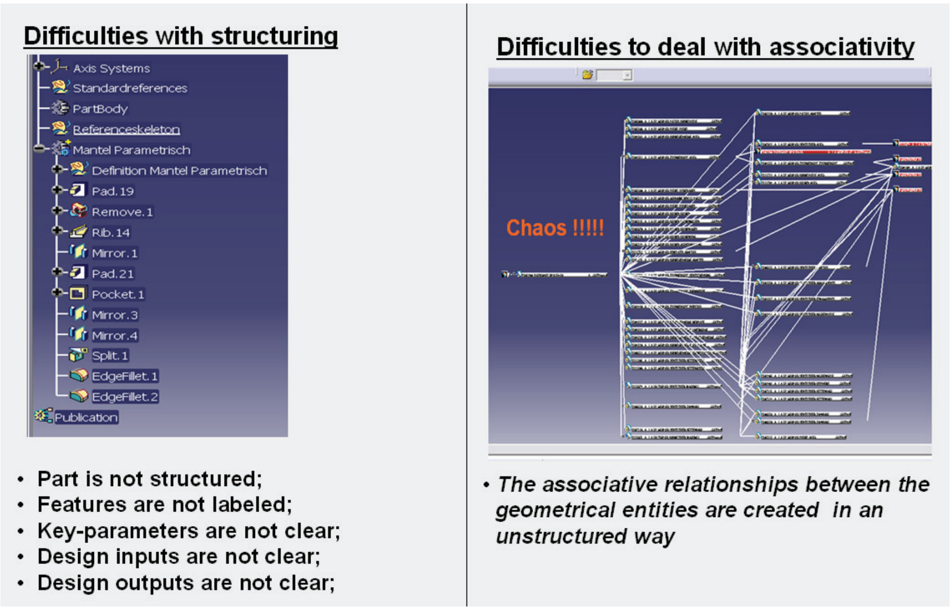


*Figure 1: Example of difficulties during the design process with PA CAD systems*

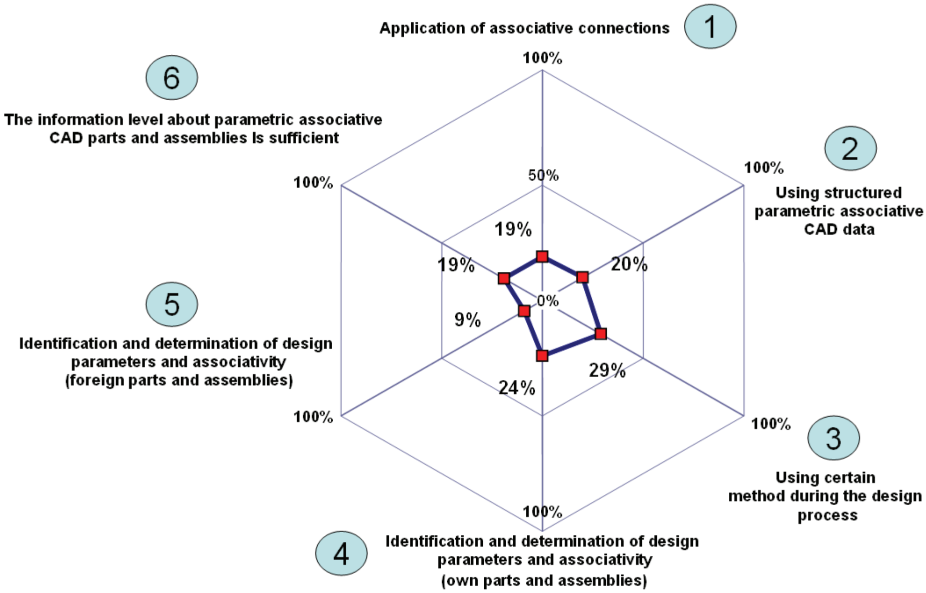


*Figure 2: Important results of the questionnaire*

### *3.2.3 Initial result of the interview in the present work*

In this part of the work the author will represent the results of the interviews which have been done with CAD coaches and designers. In this phase eleven experienced CAD system coaches have been interviewed. The basic conditions of descriptive studies are in Table 2.

The target of the questions in these interviews was to have a clear understanding of the problems, challenges and expectations of the designers of a parametric associative CAD system. The intention was to collect information about a) the experience of CAD trainers during teaching and training of parametric associative CAD systems (what kind of important factors did they identify); b) the observation of the CAD trainers related to the different "categories" of designers and how they approach parametric associative CAD systems; c) the experience of the CAD trainers related to structuring of parametric associative CAD parts and assemblies. The most important aspects and results of the interviews with CAD experts and coaches can be summarized as follows:

- 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;
- They 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 are often not well structured and therefore it is quite difficult to change them or to find relevant design information.

*Table 2. Basic conditions of the interviews*

| | |
|---|---|
| Environment | Automotive Industry and suppliers |
| Participants | 11 CAD trainers and CAD support |
| Date Collection methods | Interviewing, documentation |
| Time constraints | 120 minutes per each interview |
| Team size | 2 participants (researcher and interview partner) |
| Number of cases | 11 interview partners |
| Total duration | 2 Months (from creation phase to the analysis of the interview) |
| Role of researcher | Interview leader, documentation |

The results of the interviews showed the same important aspects that have been identified during the analysis of the questionnaire. It demonstrated that most of the designers have problems in preparing the required parametric and associative design information inputs and outputs. Furthermore for most of designers it is difficult to identify, determine and structure the parameters and associative relationships. The achieved results of the descriptive study will be discussed in the next section.

## 4 DISCUSSION OF THE RESULTS

The results of the literature review and descriptive study showed that there is a need for a generic integrated approach for working with parametric associative CAD systems. The developed generic approach should consider some general and specific requirements. Pahl and Beitz [31] described the following general requirements which are important during the development of methods in design engineering: a) Methods should be easily taught and learned; b) Methods must not rely on finding solutions by chance; c) Methods must be compatible with the concept; d) Methods must reflect the findings of cognitive psychology and modern ergonomics; e) Methods must encourage a problem-directed approach; f) Methods must foster inventiveness and understanding. The aforementioned requirements will be considered during the prescriptive study in future research. This prescriptive study is the next step of the DRM according to Blessing. The main role of the prescriptive study is to develop a frame of model or theory which is based on the results, assumptions and findings of the Descriptive Study I. In this present work this stage serves to identify or describe methods and processes and will elaborate a generic approach of working with PA systems.

The specific requirements of parametric associative CAD systems which have been identified are:

- The developed generic approach should consider a preliminary phase which helps to prepare the relevant information (parameters and associative relationships) which are necessary to create a full parametric associative CAD model. A characteristic of this phase is that it should be completely independent to a certain CAD system. The targets of this phase it to have a clear understanding of the existing relevant parameters and associative relationships between the geometrical entities. Furthermore the relevant parameters (geometrical parameters like length, physical parameters like material and process parameters like tolerances) should be identified, determined and prepared very carefully. This phase also helps to think about the relevant associative entities and their relationships to each other. The results of the questionnaire showed that most of the problems during the creation of associative relationships are caused by creating associative connections without thinking about further process steps and the consequences of such relationships. The identified important aspects are:

a) To identify and determine the relevant parameters;
b) To represent the relationships between the different kinds of parameters;
c) To identify and to determine the relevant associative entities;
d) To represent the associative relationships between the geometrical entities;
e) To reduce the complexity of parametric associative CAD models;
f) To structure the relevant parameters;
g) To structure the relevant associative entities;
h) To structure the design information inputs and outputs of CAD models;

- The developed generic approach should consider the structural aspects of parametric associative CAD parts and assemblies. That means identifying how it is possible to create a generic structure which considers the relevant design information input and outputs. The main target of this approach should be to arrange and integrate the relevant PA design information.

## 5 CONCLUSION

The presented paper demonstrates the need for a generic integrated approach of parametric associative CAD systems especially in industrial environments. Furthermore the results of the literature review and Descriptive Study I showed that there are different aspects which influence the success of parametric associative CAD models. One of these aspects is well prepared and structured parametric and associative design information which is essential to the understanding of the developed CAD models. Not until this is achieved will it be possible to use the full potential of such systems. The development of the generic approach will be the main task of the prescriptive study which will be presented in future works and papers.

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Contact: Vahid Salehi
University of Bath
Department: Mechanical Engineering
Bath BA2 7AY
United Kingdom
e-mail: vsd22@bath.ac.uk