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CLUSTERING CUSTOMER DREAMS – AN APPROACH FOR A MORE EFFICIENT REQUIREMENT ACQUISITION

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ABSTRACT

This paper introduces an approach for the acquisition of requirements centered on the idea of organizing requirements in requirement clusters. The acquisition of requirements is one of the first steps in the development process and is a key process for all following steps. The quality and quantity of the requirements acquired determine costs, necessary time and iterative steps needed in the whole development process. Due to the fact that the acquisition of requirements happens under vastly different circumstances in every project, the level of process standardization is very low. This low level of standardization results in a variety of problems: unnoticed implicit requirements, misunderstandings caused by non-standardized use of terms and incomplete or incorrect requirements. Clustering of requirements is a known concept, but up to now is used only after the process of acquisition to structure the requirements for further use. The use of requirement clusters in this paper aims at increasing the standardization and the quality by using requirement clusters in the process of requirement acquisition.

Keywords: Requirement Acquisition, Requirement Clusters

1. INTRODUCTION

Today there is no perfect approach consisting of certain rules or of certain methods, which guarantees that the process of requirement acquisition will deliver a result, which is complete and exploitable regarding the following processes. Complex connections between requirements, competing interest groups and the diverse use of terminology lead to wrong, incomplete, contradictory and non-exploitable requirement lists. The quality and quantity of the requirements are key factors, which determine the costs of and necessary time for the processes following up.[1] Due to the variety and individuality of customers and differing environments a standardization of the process of requirement acquisition leads to the need of individual adaption and adjustment for every new project. One of the biggest problems is the acquisition of implicit requirements, which are not mentioned explicitly by the customer, but nonetheless are expected to be fulfilled. [2] Processes and methods are not able to acquire all necessary requirements without any iterative backward steps, because the need of many requirements only becomes evident in process steps following the acquisition. Besides constant changes of the environment and a complex and hard to understand and overlook network of necessary requirements make several iterative backward steps inevitable. Of course certain guidelines [2] and methods like life cycle checklists, analysis of the basic conditions surrounding the product and process analysis are existing. The problem with those guidelines and methods is, that they are all on a very abstract level with no guidelines how to adept them under certain conditions and when to use them and when not. Persons with no prior experience in the field of requirement acquisition will have problems to adept guidelines and methods to their specific development project. The approach presented in this paper may be seen as a way to increase the match of needed and acquired requirements in the process of requirement acquisition. Furthermore the approach aims for a higher level of standardization and creates opportunities for a higher level of automation. This paper introduces the core idea of using requirement-clusters. Further research needs resulting out of this idea will be addressed in the conclusion.

The introduction in chapter 1 is followed by the description of the core idea in chapter 2. This chapter explains the problems of the “traditional” approach of requirement acquisition, describes different approaches of clustering requirements in the process of requirement management and differentiates those approaches from the described approach of using clusters in the process of requirement acquisition and its advantages. Chapter 3 explains how requirement clusters can be used in the process of requirement acquisition with the help of the flow chart shown in figure 4. Followed by chapter 4, which describes different approaches how to define requirement clusters for the process of requirement acquisition and the advantages and disadvantages of the different approaches. Finally chapter 5 sums up the results of the paper and gives an perspective for future research projects all centered around the cluster approach for requirement acquisition.

2. THE APPROACH

Clustering of requirements is a known concept especially in the field of computer science [3] and in engineering design [4]. However the method and most importantly the function of clustering in this approach differ essentially from the ones discussed in the references. Those approaches use clustering of requirements as a way to mark connections between requirements and group them according to their connection to each other (most times under a hierarchical point of view). Clustering in the known approaches is a way of making already acquired requirements more usable for the following processes. This means that existing approaches like a structured requirement list or requirement management tools (e.g. DOORS) are tools for managing requirements, which have already been acquired. Within this approach the clustering of requirements is done in a very different way and has a different purpose than the "traditional" way described above. In this approach the relation between requirements in one cluster is not defined, meaning that the effect of one requirement on another requirement is not defined. Of course clusters are created under a common aspect (see chapter 4) and this aspect often defines relations between the different requirements in one cluster. But this aspect is not relevant anymore after the cluster creation. Requirement clusters are just a group of requirements with no defined relations between them.

Most important the clustering in this context is a method used to improve the process of requirement acquisition. A requirement cluster in this context is a group of requirements clustered according to subject related, subject-object related and purely object related aspects (see chapter 4). The different types of clustering are explained in detail later on. A cluster can consist of complete and incomplete requirements. Regarding the example of a foursquare sheet metal profile (figure 1) this means:

- A complete requirement is a requirement which consists of an attribute and a value (could be also described as a target property). A complete requirement would be "The bowing under a 100N load should only result in 10mm deformation at the position of the force impact".
- An incomplete requirement is a requirement which consists only of an attribute. To become a complete requirement the customer has to add an individual value to the incomplete requirement. Regarding the sheet metal profile an incomplete requirement would be "The length of the profile should be xxx mm". (xxx standing for the value to be put in by the customer).

Figure 1: Sheet Metal Profile with three chambers and flange

In figure 2 requirement-clusters are represented in a graphical form. The squares are symbolizing the requirements. Filled squares are complete requirements (attributes and values) and empty squares

symbolize incomplete requirements (attributes only). The various lines around the requirements are the requirement clusters. This kind of graphical representation is also used to visualize the whole process of using requirement clusters in figure 4. As seen in the upper right part of figure 2 one requirement can be part of different requirement clusters. The identification and elimination of redundant requirements is a topic for future research in the context of requirement cluster.
Goal of the clustering approach is to increase the quality of the acquisition process by reducing the needed time, costs and manpower. Using requirements-clusters enables to acquire all necessary requirements of a certain topic related to the design process by naming just one element out of this topic field. Thereby the efficiency of the process is increased and the necessary iterative backward steps are reduced. The customer and the engineer don't have to be aware of all single necessary requirements connected to this certain field. Using this method enables the activation of tacit knowledge and the acquisition of implicit requirements. With every use of the cluster-approach the requirement-cluster catalog and the requirement catalog are enhanced and lead to a higher level of customer specialization and by that to a faster requirement acquisition with less mistakes. The following chapters show selected process steps of the approach.

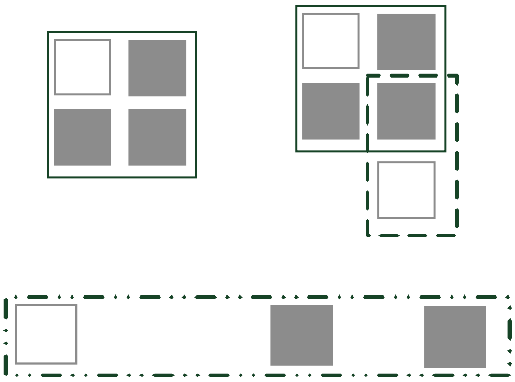

Figure 2: Graphical Representation of Requirement-Cluster

An example for a basic requirement cluster regarding the sheet metal profile could be the cluster "Dimensions" consisting of the requirements "Length of the profile should be xxx mm", "Height of the profile should be xxx mm", "Width of the profile should be xxx mm", "Number of chambers xxx", "Height, Width, Length of chamber y should be xxx mm, xxx mm, xxx mm".

3. USE OF REQUIREMENT-CLUSTERS

This chapter explains the systematic use of requirement-clusters. The following flow chart is based on the assumption that a defined catalog of requirement-clusters already exists. The definition of requirement clusters is explained in Chapter 4. Figure 4 shows the systematic use of requirement clusters, which will be explained step by step.

3.1 Activation of a Requirement-Cluster

The first step in the flow chart is the activation of one or more requirement clusters. The activation of a requirement cluster can be triggered by the customer, surrounding factors or by the product components of it. These three types of activation are shown in Figure 3 as enhanced cutout and at the very top of the flow chart in Figure 4 "Activation Types of Requirement Clusters".

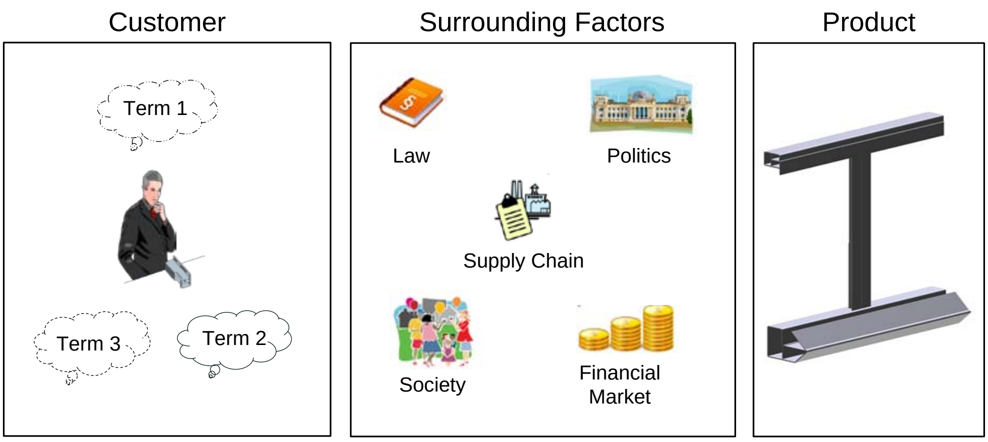

Figure 3: Activation Types for Requirement Clusters

First type activation of a requirement cluster by the customer can be done consciously or unconsciously (left part of figure 3).

- Conscious activation means that the customer chooses requirement clusters by hand, which from his point of view are needed for the development of the product. In the “Requirement Cluster Catalog” (see figure 4), each requirement cluster is linked to one or more keyword to help the customer select relevant clusters. For example the customer wants to use one of the chambers to route cables through the profile. Therefore he selects the key term “Cable Routing in Chamber” in the term catalog. The requirement cluster connected to this key phrase consists of the requirements: “Number of cables xxx”, “Cross section xxx mm of cable number xxx”, “Cable xxx bound together with cable xxx”, “Cable xxx fixed on chamber position xxx mm (x-coordinate) and xxx mm (y-coordinate).
- Unconscious activation is triggered through a certain keyword spoken or written by the customer. One keyword can activate several requirement clusters. Regarding the foursquare sheet metal profile the term “Fluid Flow in chamber” activates a requirement cluster consisting of the requirements: “Type of fluid xxx”, “Flow rate xxx liter per minute”, “Pressure of the fluid xxx Pa”, “Non corroding material”.

Both customer related activation types are linked to the idea of mental models. Most parts of the conscious and unconscious activation is based on individual, intuitive thinking and acting and not on formal objective models. Empirical studies show, that design based on unconscious thinking and acting is the dominant part in design work and is a basic factor for the success of most design projects. [5]. Mental models can be incomplete, inconsistent, illogical, individual and in an extreme case may contradict laws of nature. Furthermore mental models may change continuously based on new experiences of the individual. [6] On the other hand technical models are the opposite of mental models meaning they are based on logic and laws of nature, are independent from the user and are complete and consistent.

A second option is to activate a requirement-cluster is through surrounding factors (middle of figure 3). The spectrum of possible factors which may trigger activation is very broad. Requirement clusters can be activated by legal factors, political factors, environmental factors, financial factors, supply chain factors etc. Those clusters are activated without any actions taken by the customer. Meaning the customer doesn’t have to be aware activating them, but has on the other hand no option to choose activating them or not. An example for this type of activation could be activation by the “country of production”, which is a given surrounding factor (assuming that there is only one plant and no outsourcing option). Integrating electrical components into a chamber of the profile in figure 1 and assuming the production is based in Germany, this would trigger the requirement cluster “Forbidden and Restricted Substances” with the specific requirements “not more than 0,1 % by weight lead and mercury”, “not more than 0,01 % by weight cadmium in every homogenous material”, etc. . The use of requirement clusters triggered by surrounding conditions may support substantially in acquiring especially implicit requirements, which may be forgotten or are out of awareness of customers.

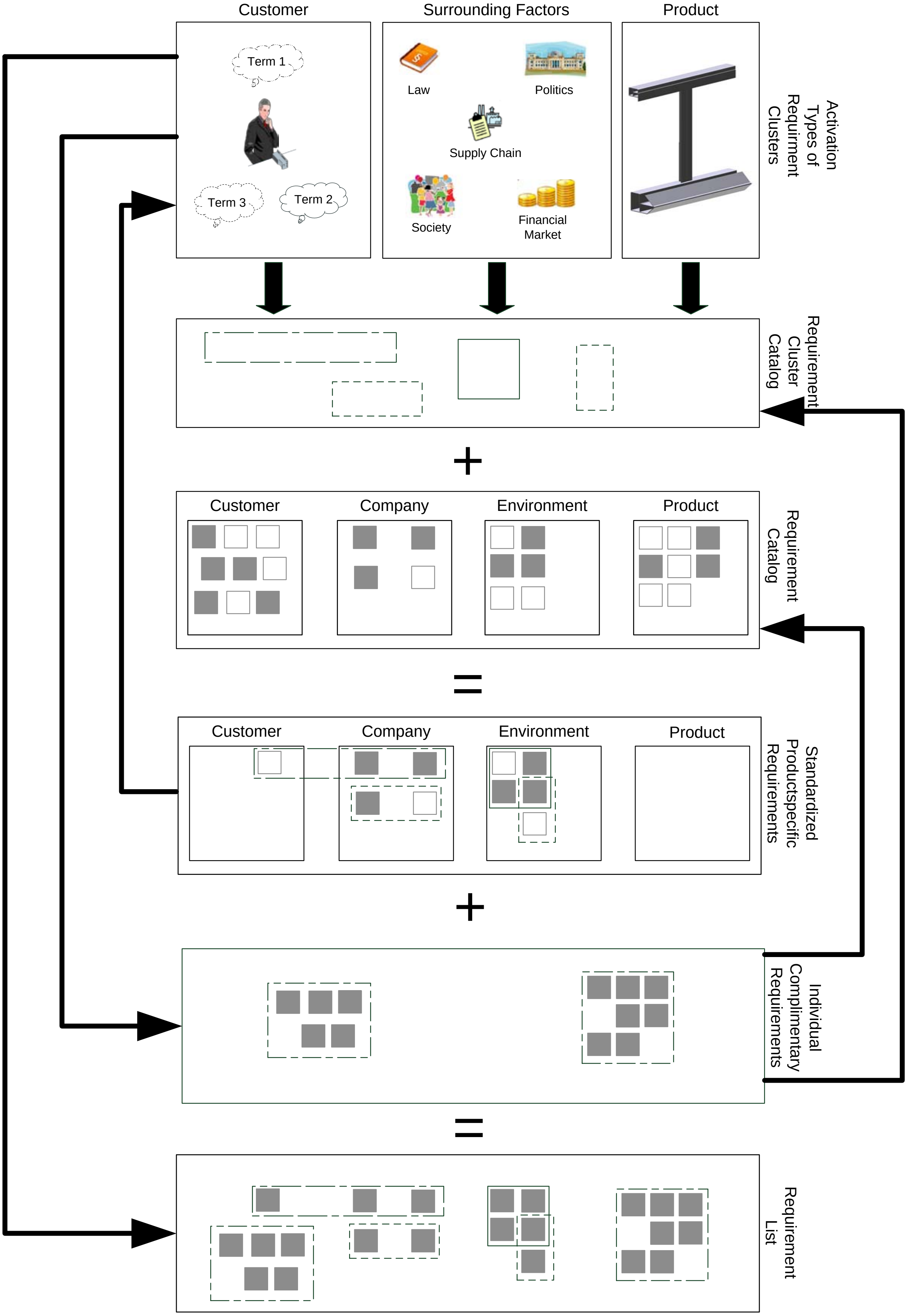

Figure 4: Process of Using Requirement-Clusters

The third option is the activation by the product itself or by a product component. If a product uses a special assembly group, which has already been used in another product, an assembly specific requirement cluster is triggered. For example two sheet metal profiles as shown in figure 1 are connected by a screw connection and flanges on both profiles. If a requirement list for a single profile is available from a former project, it can be used as a basis for the combined new product. Requirement lists can be used as requirement clusters in a modular context analog as the parts, which they are connected to, are used as components in a new assembly group. The reuse of assembly group specific requirement clusters has to be done with caution. Putting the assembly groups into a new assembly group can cause drastic changes in the requirement cluster through new interfaces. This activation type is based on formal models. Formal models are objective and based on non individual laws and facts. Formal related models can change, but compared to mental models, changes are rare and can always be reasoned on an objective and logical basis. (An example for a formal model changing could be a new law passed).
The reuse of assembly group specific requirement groups is also discussed by Stechert [7]. The use of assembly group specific groups in this context is done with its main focus on structuring the requirements in the "traditional" way and not on acquiring them. Only in the case of the redefinition of certain parameters those clusters are used as a guideline for acquiring values.

3.2 Standardized product specific requirements and complementary requirements

The activated requirement clusters out of the "Requirement Cluster Catalog" (in figure 4) define which complete and incomplete requirements from the "Requirements Catalog" (in figure 4) are used in the following design process. The result of this activating process is a collection of product related standardized requirement clusters and product specific requirements.
This portfolio ("Standardized Productspecific Requirements" in figure 4) is given to the customer for two reasons (Arrow from "Standardized Productspecific Requirements" to "Customer" in figure 4)

- First of all the customer has to complete all incomplete requirements by assigning them a value. If the customer doesn't see the necessity of defining a value or a value interval for an incomplete requirement, the value of the requirement is left variable to give room for optimizing the product regarding a certain attribute connected to this value.
- The second reason involving the customer at this point of the process is that the customer can add requirements or whole requirement clusters, which from his point of view are missing. These customer specific complimentary requirements and requirement clusters ("Individual Complementary Requirements" in figure 4) are combined, aligned and adjusted with the "Standardized Productspecific Requirements" to form the "Requirement List" (see figure 4).

The complementary requirements and requirement clusters can be used as an addition to the requirement cluster catalog and the requirement catalog. There needs to be an examination of the complimentary requirements regarding their level of objectivity before integrating them into the requirement clusters. Objectivity in this context means that a requirement or a requirement cluster can be reasoned by a logical or physical law. Requirements with a high level of objectivity can be used as permanent additions to the respective catalogs. Requirements and requirement clusters with a low level of objectivity should be used as customer specific additions to the requirement and requirement cluster catalogs. These customer specific additions to the catalogs guarantee an improvement of the whole requirement acquisition process with every usage by the customer. By building up large customer specific catalogs the likelihood of misunderstandings due to customer specific terms and phrasing is decreased and the quality of the acquisition process increased. Moreover the whole acquisition process needs less time with every new usage due to customer specific terms and clusters.

4. CREATION OF REQUIREMENT CLUSTERS

The core question of the requirement cluster approach is the question of how requirements should be grouped together. One possibility for expanding existing requirement clusters has been described before. They can be complemented by requirements and requirement clusters defined by the customer as a result of the use of requirement clusters. ("Individual Complementary Requirements" in Figure 4). The question is how requirement clusters may be defined at the very beginning.
This contribution differentiates between three basic approaches of creating requirement clusters. The basis for every definition of requirement clusters is an existing requirement catalog. This requirement catalog can be the product of the previous (non cluster-oriented) requirement acquisition of similar

projects or a standardized requirement acquisition performed as a pre-process for the actual design task as described by many authors. [2] [8] [9] The three different approaches to cluster requirements are: the subject related approach, the subject-object related approach and the object related approach (see figure 5-7). It is important to mark every requirement cluster by which approach it was created. Depending on this differentiation the requirement cluster can be used in general or only in customer specific contexts.

The subject related approach is clustering requirements in a subject related way as shown in figure 5. This approach is called subject orientated approach, because the customer creates requirement clusters from his subjective point of view and links them to certain keywords. On one hand from a technical and logical point of view this approach may be judged critically. On the other hand keeping in mind that these clusters are marked as customer specific clusters and are not used in a general context they provide a highly efficient way of customer individualization. These clusters are based on customer specific mental models as described before.

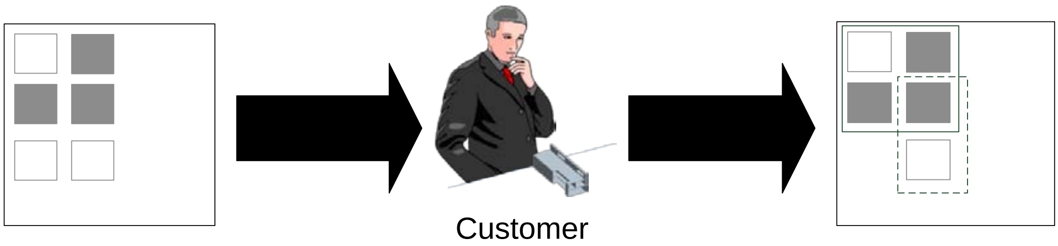

Figure 5: Subject related Approach of Clustering Requirements

The subject-object related approach is clustering requirements in a subjective-objective way as shown in figure 6. After a conventional requirement acquisition an uninvolved person (in the following named “observer”) examines the process, the behavior of the customer, errors and misunderstandings that occurred and the level of effectiveness after the process with the aim optimizing the weaknesses of the specific process of requirement acquisition. Based on these observations the observer defines requirement clusters. The requirement clusters are still based on the behavior and statements of the customer, but through the observation and interpretation of the observer they gain a certain level of objectification. The observer has the possibility to compare the acquisition processes of different customers and define clusters. The level of objectivity for clustering may increase with every acquisition process the observer experiences and can compare to other design projects. Subject-Object related requirement clusters can have general characteristics, but can also be purely subjective. So the quality and usability of the clusters depend highly on the experience of the observer and the use of methods and guidelines. The clusters created this way are based on a combination of mental and formal models:

- Mental models determine the behavior of the customer during the process of requirement acquisition and the subjective influence of the observer.
- Formal models are used to observe and evaluate the process and rules creating clusters on these results.

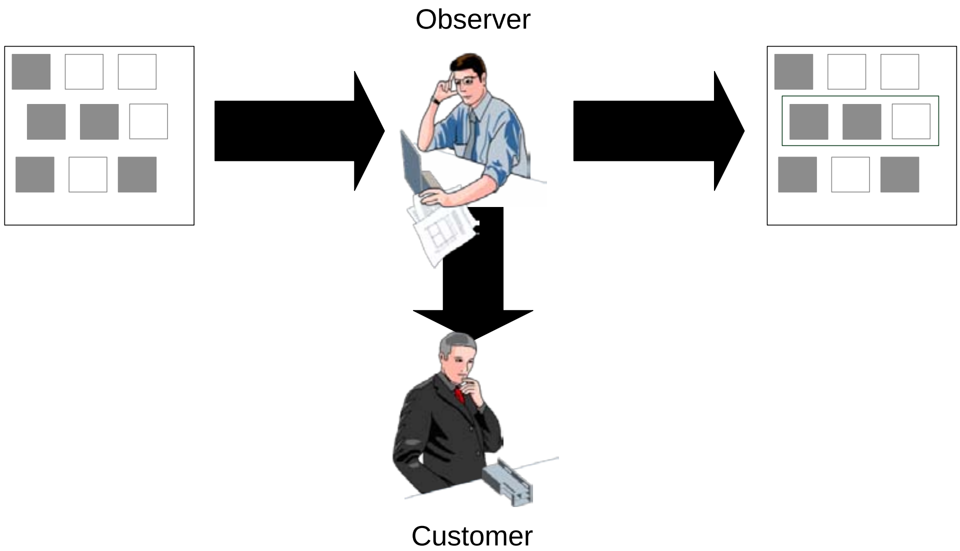

Figure 6: Subject-Object related Approach of Clustering Requirements

The object related approach defining requirement clusters is the most objective way as shown in figure 7. Using this approach clusters are defined based on objective relationships and therefore are independent of the person defining the cluster. On the one hand object related clusters can be created from dependencies resulting from the product and process environment. E.g. if the production site is located in a certain country the cluster connected to this property will have requirements resulting from restrictions by law of this country. These restrictions will always be in the cluster no matter who is defining it because the production restrictions apply to everyone. On the other hand a requirement cluster can be defined based on natural laws. A requirement cluster linked to the phrase “volume of a chamber of the sheet metal profile” consists of the requirements “Height of the chamber xxx mm”, “Width of the Chamber xxx mm” and “Length of the chamber xxx mm”. This cluster is based on the mathematical law that the volume of a rectangular body is “Height x Width x Length” For more complex links of properties, property networks as described in [10] could be used to define requirement clusters. The advantage is that all values necessary for using the property networks for an optimization of the product will be acquired this way. This approach of defining requirement clusters is based on technical models as described before.

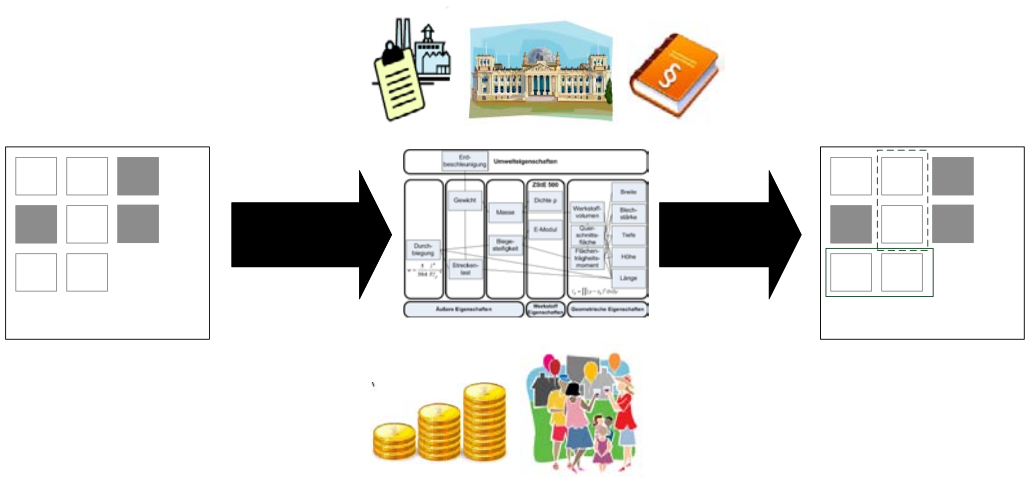

Figure 7: Objective Approach of Clustering Requirements

For subject ,subject-object related and in some cases even object related requirement clusters it is important to keep in mind that requirement clusters are dynamic objects and should be adapted to changed basic conditions. A changed product environment and changing needs of the customer make it necessary to update the clusters throughout the whole design process. Only through the dynamic approach it is possible to achieve the highest level of quality regarding the requirement list and thereby to reduce costs and project duration.

5. CONCLUSION AND FURTHER WORK

The use of requirement clusters should be seen as a step towards standardizing the process of requirement acquisition and thereby giving the chance of automation or semi-automation of process steps. Quantity and quality of the created requirement list is increased and the number of iterative backward steps is reduced by acquiring implicit requirements as well as complete requirement sets on the first run. The advantage is that customer and engineers don't have to regard every aspect of a certain product related topic. The acquisition of all necessary requirements of one related topic is achieved by only naming one of several related key words. Moreover the customers and the engineers don't have to think of requirements, which are not found in the direct environment of the product, but are nether the less important and need to be fulfilled by a successful product. So tacit knowledge, which is needed in the design process is activated without explicit actions of the customer or the engineer. Using the approach proposed as shown in figure 4 leads to a self-optimizing system that improves with every use and adapts more and more to the needs of the customer. As a result the time needed for each requirement acquisition should decrease from usage to usage. Partly because the customer gets used to the system, but mostly because the requirement-cluster catalog and the requirement catalog are adapting to his needs with every usage.

As stated before: this contribution highlights the framework for further research. The purpose of this paper is to demonstrate the core idea and lead to questions that will be addressed in further research and future publications:

- Detailed guidelines about the process of creating subject, subject-object and object related requirement clusters need to be created. There is the need for a detailed examination, which mental and technical models are behind approaches of creating requirement clusters. Knowing the functional links behind the models leads to creating more efficient requirement-cluster and using the right models under the right basic conditions.
- Another research question is which kind of cluster type should be used in which situation and in combination with which other cluster. Different basic conditions of the development project are leading to different clusters, which are optimal under specific basic conditions.
- The topic how clusters should be linked to activation keywords is another question to be answered. Regarding this question there is the need to examine the standardization of terms and how people create links between terms and requirements in their mind. This research topic is also linked to the field of mental models.
- In which form should the customer receive requirement clusters for the general completion of cluster and requirements and the completion of incomplete requirements? The mass of selected requirements in clusters could overwhelm an untrained person. Selection rules and the conversion of requirements for example into more "visual" scenarios, which show the impacts of a requirement on the product and the product environment, could be a solution for this problem. There is the need to develop distinct rules, which clusters the customer should be confronted with and with which not. This question is closely linked to a differentiation and categorization of the customers by their skills and knowledge regarding the development project.
- Moreover a closer examination of the activation rules of requirement clusters is needed. Are there certain basic conditions which favor or block out certain activation approaches?
- Another important question is in the field of adding complementary requirements and clusters and by the customer. A method which helps to determine the level of objectivity and sort the clusters in general or customer specific additions would be helpful.
- As shown in Figure 2 there is the possibility that one requirement is in more than one requirement cluster. The question is how to sort redundant requirements out. Of course this process is easy, if the requirements out of the requirement catalog are standardizes. But what happens with additional requirements by the customer, which are named and described in a non standardized way. The use of thesauri for the process of standardizing terms seems to be one promising approach to solve this problem.
- In the end there needs to be an evaluation of the concept of requirement-clusters. Is the concept working and how big are the savings of time, costs and manpower by using requirement clusters

compared to the “traditional” concept? A first approach could be the observation of student test groups, acquiring requirements of the same products with and without the use of requirement clusters. Differences in the time needed and iterative backward steps needed should be visible.

Therefore this contribution may be seen as a starting point for research work into many different connected fields of design research and a possible approach to achieve a higher level of quality, standardization resulting in a higher level of automation in the process of requirement acquisition.

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