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STANDARDIZED REQUIREMENT ACQUISITION THROUGH CLUSTERING: A TOOL FOR ENERGY-EFFICIENT PRODUCTS

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1. Introduction

One of the key problems in the early stage of the design process is that there is only a very low level of standardization. Although there do exist some methods for the task clarification and requirement acquisition process [Pahl et al. 2007], the difficulty for the designer consists in the fact that those methods are described only on a very abstract level. Moreover the product developer has to decide which method should be used in which specific situation, in order to gather requirements comprehensively and in an unambiguous way. But in particular for the selection and the necessary adaptation of methods no general rules or guidelines exist. This low degree of standardization is also relevant for the specification and detailing process of requirements. If the designer for instance receives the order to develop an energy-efficient product, tools and methods are missing that help him specifying and detailing such a requirement.

But especially the requirement of developing energy-efficient products becomes more and more relevant. The requirement "energy-efficiency" is increasingly present on requirements lists, from consumer goods to investment goods. Whereas for customers energy-efficiency significantly becomes a decisive purchasing factor, energy-efficient products that require not only in the use phase but also in the production phase as little energy input as possible, bear important cost saving potential for companies and serve as an important marketing instrument. Moreover more and more laws and directives require that certain energy-efficiency criteria are met.

Whereas for the later stage of the product development process some guideline-based energy-efficiency-tools exist e.g.[Bonvoisin et. al 2010], there are no tools provided that help the designer in the early phase of the product development process to detail and specify the requirement "energy-efficiency". But exactly in this early phase a support of the designer would be helpful. Often the requirement "energy-efficiency" is mentioned buzzword-like and afterwards pushed into background, as the knowledge for detailing this comparative, qualitative requirement on a precise, quantitative level, specified for a certain product, is missing.

Here the problem of a lack of standardized requirement acquisition processes becomes relevant as well. A possible orientation guide that provides reverence points for designers on how the requirement "energy-efficiency" can be specified derives from laws and labels.

Whereas laws impart precise requirements without whose fulfillment a product can't be marketed, labels consist of precise requirements that have to be met in order to indicate a product with that label. The help of laws and labels in detailing and specifying the imprecise requirement "energy-efficiency" is far again countered as a multitude of different laws and labels exist that vary for different countries and consist of a wide range of different requirements.

This paper therefore presents a tool that serves the designer to acquire detailed, specified requirements concerning energy-efficiency. This tool can be applied both to acquire necessary requirements from

laws and labels and to serve as an information tool in the field of energy-efficiency. Thereby the tool is based on the requirement-cluster approach for an optimized and complete requirement acquisition of Röder et al. [Röder et al. 2011].
In this paper the cluster approach is applied to the example of energy-efficiency requirements arising from laws and labels and therefore validates the core idea of the cluster approach.
Therefore in chapter 2 the basic principles of the requirement-cluster approach as well as the fundamentals in the field of environmental laws and labels are explained. Chapter 3 describes the necessary steps to define the energy-efficiency requirement-cluster catalogue and chapter 4 shows how the clusters can be activated. In chapter 5 the application possibilities of a potential energy-efficiency cluster-tool are described with the help of an example. Finally in chapter 6 further steps and the limitations of the approach are discussed.

2. State of the art

2.1 Requirement clusters

The idea of grouping or clustering requirements is a widespread concept in the field of software and product development [Al-Otaiby et al. 2005], [Maeltz et al. 2007]. But requirements are until now only clustered after they have already been acquired. The sole purpose of clustering therefore is to group already gathered requirements, in order to ease further work with them. However the concept of Röder et al. utilizes clusters before requirements are acquired, in order to ease the elicitation of relevant requirements [Röder et al. 2011]. Concerning this new approach a pre-defined catalogue of requirement-clusters exists, at which every cluster is linked to one or more topics. Is one of those clusters considered to be relevant to a current development project, the cluster and its subclusters, containing several requirements, are transferred to the requirements list. The application of this approach allows that via one single activation-criterion all relevant requirements concerning this topic are determined. This saves time, money and iterative steps in the development process. Moreover it is possible to capture implicit requirements with this concept. A requirement within a requirement-cluster can be complete or incomplete. Complete requirements in this context are defined as requirements consisting of an attribute and value, whereas incomplete requirements consist of an attribute only. The further specification of incomplete requirements can be determined by the customers or designers if they wish to.
Röder et al. define three different ways how a requirement-cluster can be activated in the development process: activation through the customer, surrounding factors or the product itself [Röder et al. 2011]. The activation of a cluster by the customer can be carried out in a conscious or an unconscious way. A conscious customer-activation means that the customer selects those requirement-clusters from a cluster-catalogue that are in his opinion relevant to the development project. The cluster-catalogue is ordered by certain terms and topics and doesn't confront the customer with the detailed requirements. At the unconscious customer-activation an analysis of what is being said or written by the customer is carried out. If certain terms and topics are mentioned, the relevant cluster is activated. Through this unconscious activation a higher objectivation is reached in the cluster-selection. The activation via surrounding factors and the product itself are activations-types that are proceeded without the influence of the customer. The activation by surrounding factors means that requirement-clusters are activated, that relate to unchangeable facts concerning the development process, like for instance the country of the main production site, the existing market or the laws of a country. A requirement-cluster can also be activated by the product itself. Due to certain characteristics of the product or its components clusters can be activated. If for instance an electronic device is developed, the requirement-cluster of necessary interfaces for this type of product could be activated.
This different activation types guarantee the collection of important requirements that are not in the focus of a customer. Moreover the cluster-catalogue serves as a kind of knowledge storage that relates different requirements to each other and provides knowledge for detailing them.
A catalogue and its requirement-clusters can be defined and created in different ways. Basically a subjective and an objective way of cluster-creation can be distinguished. Subjective cluster-creation means, that a collection of requirements is provided to the customer, who has to cluster them relating

to his mental model of the world and has to assign certain terms and topics to the requirements. This way of cluster-creation leads to clusters that have a high efficiency-grade at the requirement acquisition process with this customer, as they represent this customer's mindset. But these clusters can in most cases only be used in development processes with this customer and have to be complemented by objectively created clusters. Objective clusters are clusters that always have the same contents and structure, independent of the person who created it. These are clusters that have been created on the basis of laws or physical facts, not leaving room for personal interpretation, and can be utilized for every customer-group.
Overall this cluster-approach represents an applicable support for an optimized requirement-acquisition that allows a more complete, faster and therefore more cost-efficient acquisition of requirements. Moreover requirement-clusters can serve as knowledge-storage to support the developer. More details can be found in Röder et al. [Röder et al. 2011].

2.2 Overview of environmental regulations

Figure 1 provides an overview of environmental regulations concerning products. In general a distinction between laws and labels can be made.

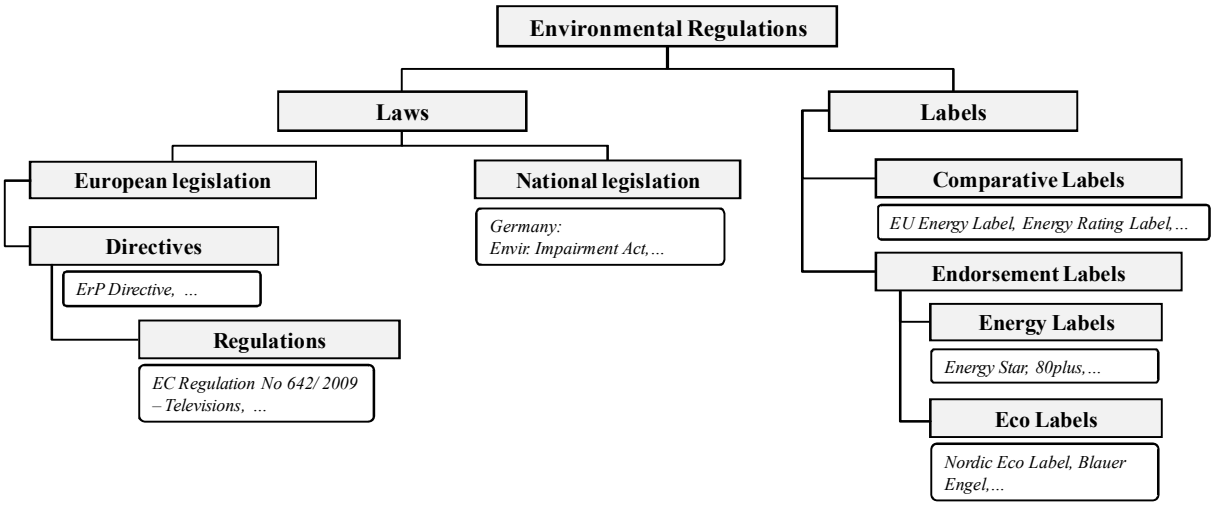

Figure 1. Environmental regulations concerning products

Concerning their origin, environmental laws can be differentiated into national and supranational legislation. Figure 1 shows the example of Germany, for which on a national level environmental legislation like the "Environmental Impairment Act" or the "Product Liability Act" and on a supranational level the European legislation applies to products. Nowadays within the European Union most of the product related environmental legislation has its origin on the European and not on the national level.
Within the European legislation, directives and regulations have to be distinguished. For instance the energy-related products (ErP) directive (also called Eco-Design directive) aims to reduce environmental impacts of energy-related products. The directive itself doesn't define any specific product requirements [Council of the European Union 2009]. But this Directive is implemented in several product-specific regulations (like for instance the European Commission regulation No 640/2009 concerning electric motors or the European Commission regulation No 1016/2010 concerning household dishwashers) that define legally binding environmental requirements.
Labels can be differentiated into comparative labels and endorsement labels: whereas comparative labels are mandatory for certain products – e.g. in the European Union products like washing machines or refrigerators have to be labeled with the "EU Energy Label" [Council of the European Union 2010] – endorsement labels are labels that can be placed on products voluntarily, depending on company-specific marketing and development goals. Comparative labels only deal with energy-efficiency aspects of products. They classify products into predefined energy-efficiency classes and clearly show the energy consumption of products to potential customers. Comparative labels have to

be placed well in view of the customers so that the classification of a product into a low energy-efficiency class automatically leads to negative characterization of the product [Sammer et al. 2006].
Furthermore voluntary endorsement labels exists, that can deal only with energy aspects (so called Energy Labels like the "EnergyStar" or "80plus") or deal with environmental impacts of products in general. So called Eco Labels like the "EU EcoLabel", "Nordic EcoLabel" or the "Blaue Engel" have beside energy-efficiency aspects also a focus on further environmental aspects of products, like the resource-efficiency.

3. Creation of requirement-clusters arising from laws and labels

Laws and labels only leave little room for personal interpretation concerning the therein contained product requirements. Law and label requirement-clusters therefore should be created in an objective way (see chapter 2.1). For the objective creation of requirement-clusters arising from laws and labels, in a first step, requirements from the relevant laws and labels have to be extracted, this requirements have to be analyzed concerning their correlations, and finally clusters have to be structured in a classification scheme. This approach is shown in figure 2.

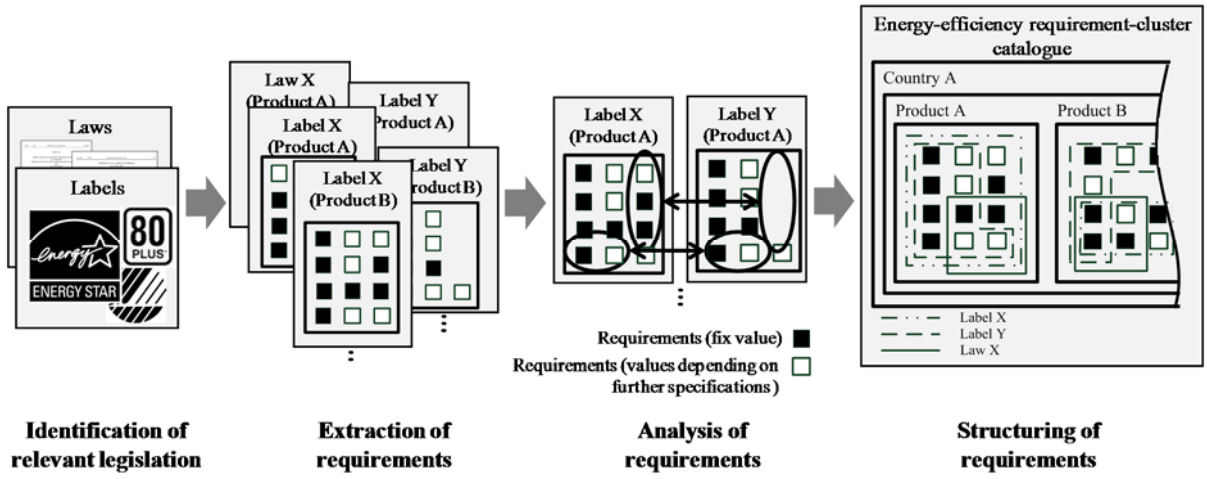

Figure 2. Relevant steps to create the energy-efficiency requirement-cluster catalogue

In total 23 environmental regulations relevant in the field of energy-efficiency had been analyzed concerning their requirements, including 2 European directives, 8 European regulations, 5 national laws from different countries (in- and outside Europe), 4 comparative and 5 endorsement labels from different countries, dealing with various products.

3.1 Extraction of requirements from laws and labels

In a first step the product requirements had been extracted from the identified laws and labels.
The steps that have to be performed in order to extract product requirements from legal text are dependent on the type of regulation. In the case that legal texts contain ambiguous wording, predominantly qualitative descriptions and no clear separation of figures and texts, extracting requirements is more difficult than for legal documents that are clear and understandable, and thus leave no room for interpretation.
Therefore the steps that must be performed to extract requirements from laws and labels are more or less time-consuming, depending on the type of legal text. Those steps mainly consist of:

- Clarification of ambiguities, redrafting, shortening of text
- Separation of the requirements by property and value (if value is given)
- Specification of requirements into demands or wishes

The analysis of the different regulations revealed, that the effort of extracting requirements from comparative labels, EU regulations and Energy Labels is the lowest. Those environmental legislations deal solely with energy, in which key aspects such as the power consumption in different operating conditions are accurately quantified and no room is left for interpretation. In contrast the extraction of

requirements from some national laws, requires much more effort. Such legal texts usually consist of different clauses containing exceptions and references to other laws, resulting in a complex network. Moreover terms are often not defined in a clearly way and it is the responsibility of jurisdiction to clarify what is ultimately meant by certain statements. In order to remove uncertainties and finally extract requirements from those laws, deeper research has to be carried out, consuming a tremendous amount of time.
When ambiguities are clarified, texts eventually are shortened and reworded, the requirements have to be separated by property and value (if an exact value is given) and finally be specified as demands or wishes. This specification arises on one hand from the character of the regulation. Laws and specific comparative labels are obligatory and not optional in particular territories. Endorsement labels on the other hand, represent optional supplements that are to be seen as a marketing tool, with which customers are informed about the product quality. Hence requirements resulting thereof have to be specified as wishes. Only if a company or customer determines the receipt of a certain endorsement label as a development target the requirements have to be specified as demands in the requirements list.

3.2 Analysis of the extracted requirements

In a first step, the extracted requirements had been analyzed concerning energy-aspects. This analysis revealed that energy-efficiency requirements extracted from laws, comparative labels and energy labels refer solely to the use phase of products. Moreover those requirements only refer to active products and aim to reduce energy demand through efficiency increases in the product or by influencing user behavior (e.g. by the presence of visible controls etc.). Only some Eco Labels contain energy-efficiency requirements relating to the production phase of products, whereby only passive products, that don't require energy in the use phase, are addressed here. E.g. the "EU Eco Label" requires the use of energy-efficient manufacturing processes for the production of hygienic paper.
In a second step the correlations between the energy-efficiency requirements, extracted from laws and labels, had been investigated. Thereby it became clear that the requirements are partly interdependent and refer to each other. In order to achieve e.g. the "Energy Star", a product has to reach a certain energy-efficiency index. For the calculation of the energy-efficiency index the Energy Star refers to formulas contained in US law. Also different labels refer to each other: if the goal is to reach the label "Blauer Engel" for certain products, all the requirements of the "Energy Star" have to be met beside others. This shows that intersections exist and some labels are even a requirement-subset of other labels.
Labels and laws of different countries normally distinguish products into same groups. Comparing the energy-efficiency requirements of different laws and labels on those product groups, it is apparent that some laws and labels have more and some have fewer requirements on a product. But there always exist requirements that are contained in several laws and labels. For instance all the identified, relevant laws and labels containing energy-efficiency requirements for televisions, include the requirement of not exceeding a certain power consumption value in the operating mode.
The requirement "Maximum power consumption in the operation mode" is in some legal text also described as "Maximum power consumption in the on-mode". As operation and on-mode is defined in the same way, a consistent description has been chosen. Such a consistent terminology had been chosen for all requirement properties, so that intersections between laws and labels can be shown and an unambiguous cluster can be build.
If requirements from different laws and labels exist, that concern the same attribute, the values of that requirement-attribute contained in the different laws and labels, may differ. In general a label imposes stricter requirements as laws, which in general require a minimum standard only. For instance EU-laws for televisions require the value of 0.3 watts for the requirement-attribute "Maximum power consumption in the off-mode", whereas the label "Blauer Engel" requires not exceeding a value of 0.1 watts.
In the analysis only complete requirements could be identified, consisting of a property and value. But some requirements impose a value that is dependent on certain product-specifications. Comparative labels moreover impose requirements that are dependent on the desired energy-efficiency goal.

Generally there have to be carried out calculations that determine the required value depending on the specifications and set targets.

3.3 Structuring requirements derived of laws and labels

From the analysis above it became clear, that a classification of the energy-efficiency cluster-catalogue into country- and product-specific clusters makes sense (see figure 3).
Structuring the cluster-catalogue according to the country in which a product will be marketed, is beneficial, as different laws apply in each country. In addition, in every country different comparative labels are mandatory: while in the EU-countries the comparative label "EU Energy Label" is mandatory for certain products, on the Australian market, the comparison label "Energy Rating" is effective. Endorsement labels like e.g. the “Energy Star“ on the other hand always have the same requirements for a product-type, no matter where it is marketed. However, labels have different customer relevance in different countries. E.g. the label "80plus" is known only on the North American market and is therefore only relevant for those countries. Therefore the energy-efficiency clusters of countries outside the North American market do not contain the resulting requirements from “80plus”.
Every country-cluster contains the requirements from different laws and labels, ordered by the products that are differentiated in those laws and labels. If a product developer wants to market a certain product in a country, the energy-efficiency cluster “Country A, Product X” provides an overview of all mandatory requirements from laws and comparative labels, as well as all possible additional requirements from endorsement labels relevant for this market. They are summarized in so called sub-clusters.
The structure of the developed energy-efficiency cluster-catalogue with its clusters and sub-clusters is shown in figure 3. The figure shows the interdependencies and overlaps of the sub-clusters. If for instance in addition to an already activated law-cluster a voluntary endorsement label-cluster is chosen, additional product requirements can arise.
Moreover the dependencies of requirement-values from:

- the chosen label and/or
- product specifications

are exemplary shown in figure 3.

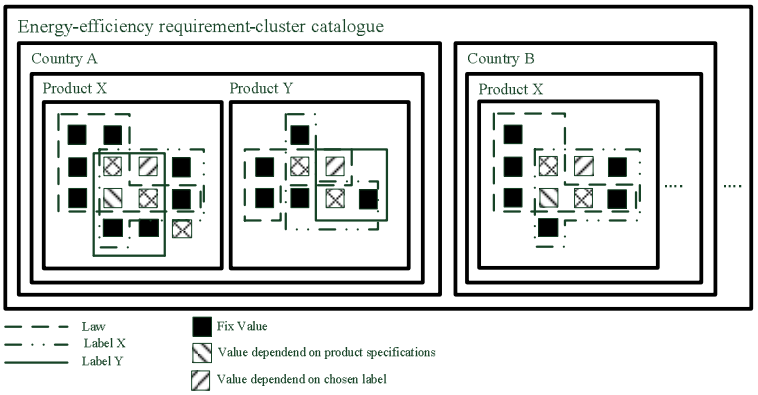

Figure 3. The structure of the energy-efficiency requirement-cluster catalogue

Depending on the chosen endorsement label, values of requirement-properties can probably change. EU-laws for televisions e.g. have the requirement that the maximum power consumption in the standby-mode may not exceed 0.5 watts. If designers or customers choose to provide the TV also with the label “Blauer Engel”, the value of the property “Maximum power consumption in standby-mode” changes from 0.5 to 0.3 watts and the additional requirement “Integration of a brightness control” has to be included in the requirements list. But the values of requirements do not only depend on the chosen label, but also on product specification. For instance the value of the requirement “Nominal minimum efficiency” for electric motors is dependent on certain product-specifications, like e.g. the number of poles and the rated output power of the motor.

This classification scheme is in addition appropriate for a comparison between different countries. For instance by comparing the requirements a product X has to meet in country A with those for country B, a modification-cluster could be provided. The product developer gets a fast overview of attributes that have to be added or eliminated and values that have to be modified in order to meet all legal minimum standards of a new market and meet all the additional requirements from the chosen, nationally relevant endorsement labels. With the help of the requirement-cluster catalogue the product developer therefore can save a lot of time when introducing a product on a new market.

4. Activation of the clusters

The application of the created energy-efficiency cluster catalogue with its sub-clusters can take place according to the introduced general activation principle (see chapter 2.1). The cluster therefore can be activated by:

- the customer in an conscious or unconscious way
- surrounding factors
- the product itself.

For instance a customer or product developer can for instance choose from the catalogue, which label a product should have. Based on this conscious, active decision, the requirements linked to this label have to be added to the requirements list. The customer or designer therefore is not bothered with the acquisition and detailing of requirements and doesn't have to know them, but only chooses the designated result. In this case a cluster also functions as knowledge storage. Besides this conscious activation also unconscious customer activation should be possible. Therefore a tool based on the requirement-cluster catalogue has to be realized, analyzing written or mentioned terms and topics.

The activation by surrounding factors refers in this case especially to laws that are mandatory for certain countries. If for instance the chosen market of a certain product is Germany, the requirement cluster with the laws and necessary comparative labels of Germany for this kind of product should be activated automatically. This ensures that requirements that are not acquired or misdescribed do not compromise the entire development project and that relevant topics outside the focus of the developer are recorded anyway.

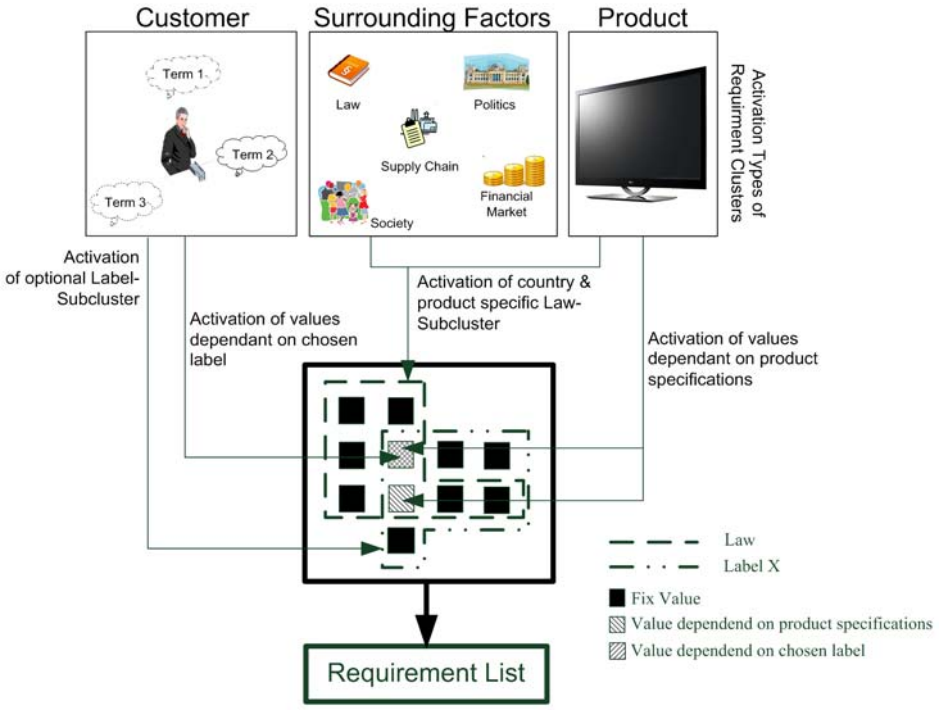

Figure 4. Combined activation of requirement-clusters

Clusters therefore are also activated by the product itself, in combination with the targeted markets. Moreover the values of certain requirement attributes are activated by the product and its specifications. Whereas the requirement attributes to reach a law or a label do not vary for a certain product, values for certain attributes can vary: e.g. electric fans have to reach a certain efficiency grade, depending on the power input and the fan type. For instance different values exist for axial fans or mixed flow fans.
This shows that a complete requirement acquisition can only be reached through a combination of the different activation types. The product and the country for instance determine certain requirements set by law. The customer request to meet a certain endorsement label activates additional requirements and moreover changes values of requirement attributes that have already been activated by laws. Furthermore some values of requirements can only be set by the product and its specifications.
The following figure 4 shows an overview of the combination of the different activation types.

5. Application possibilities of a potential energy-efficiency cluster-tool

In this chapter the application possibilities of a potential energy-efficiency-cluster tool on the basis of the above described energy-efficiency cluster catalogue and its activation types will be described using the example of a television.
Such a tool should on the one hand provide a user interface for an automated requirement acquisition. If a designer gets the instruction to develop an energy-efficient TV for the German market, the designer can enter the keywords “TV” and “Germany” into the interface and the tool automatically activates the cluster “Germany, Television” and transfers the requirements of the mandatory law-sub-clusters directly into the requirements list. As the requirement “Maximum power consumption in the on-mode”, regulated by law, depends on further product specifications like the visible screen area and the resolution type (full HD resolution or other resolutions), the tool could for instance automatically inquire further product details via an input field or leave the value for this requirement in the requirements list at first open. If it’s a customer request or development goal, that the TV at least has to be labeled with for instance the energy-efficiency class A of the mandatory EU-Energy Label, the value of the “Maximum power consumption in the on-mode” has to be changed accordingly. For a full HD TV with a visible screen area of 12.5 dm² the tool would change the value from the minimum law standard of 74.03 watts to 38 watts. If the additional label “Blauer Engel” has to be reached, the value of the maximum power consumption in the on-mode does not change, as the energy-efficiency class A already requires the same value. But the value of the power consumption in the off-mode and the standby-mode will change. In addition requirements like “Automatic brightness control in the on-mode” will be automatically added to the requirements list.
The cluster-tool should beside the automated requirement acquisition also serve as a target-oriented information tool for the user. A designer can use the tool for getting an idea on how the requirement “energy-efficiency” could be specified as well as quantified for TVs and what is really considered as energy-efficient concerning the state of the art in certain countries. Especially comparative labels give a good idea of what is considered to be energy-efficient in terms of the current state of the art.
Moreover the tool could inform the designer, which endorsement labels are relevant for TVs in different markets. Also the tool should give information about which laws and labels are most stringent. For the product developer it is for instance interesting to know, that with meeting the requirements of the energy-efficiency class A on the comparative EU Energy label the “Blaue Engel” the “Energy Star” is reached automatically. Also a quick comparison of requirements in different countries should be possible with the tool. If a TV, already marketed in Germany, has to be introduced to e.g. the US, no further laws have to be considered, as no laws exist for TVs on the US market. A market introduction in Australia would lead to different laws that have to be met. But as the European minimum standard for the power consumption in the on-mode is more stringent (at least for certain product types having a specific visible screen area), no more additional requirements than the placement of the Australian comparative label on the product has to be considered. The tool should automatically inform the developer, that a TV meeting the A standard of the EU Energy label would lead to a certain number of stars on the Australian label.

6. Limitations of the approach and further steps

The previous example shows that a standardized requirement acquisition with the help of an energy-efficiency cluster tool offers a lot of advantages. The product developer saves a lot of time, as he doesn't have to study legal texts all over again and doesn't have to catch up on the customer relevance of labels on certain markets. Moreover requirements can be acquired with the help of a few key words both in a fast, right and detailed way, avoiding iteration loops in the development process. In addition a comparison of the requirements of different labels or between different countries can be carried out very fast and the frequently demanded requirement "energy-efficiency" can be detailed automatically.
However such an energy-efficiency cluster tool on the basis of laws and labels also has limitations. On the one hand it is very time-consuming to build a complete energy-efficiency cluster-catalogue for all relevant countries and their laws and labels. Especially language difficulties exist, as some laws and labels are solely documented in the national language (in the context of this work therefore only laws and labels had been analyzed, that were available in English or German). Besides the tool has to be realized in a way that the cluster-catalogue can be expanded and updated, as laws and labels constantly change. For instance the energy-efficiency classes of the EU Energy Label change continuously in order to adapt to changes in the state of the art. E.g. for refrigerators not the class A, but the newly introduced class A+++ is the most energy-efficient nowadays. In order to simplify those necessary updates, an automated requirement extraction out of laws and labels on the basis of standardized work steps would be helpful. If and how this could be realized, however, it is yet to be determined.
Furthermore, it remains open in which context such a law- and label-tool is most useful. The question has to be clarified, whether such a tool could possibly be an impediment in finding new creative solutions in the development process. To clarify this question appropriate field tests with design-teams would have to be performed. Moreover the question arises if an ecologic development should only be based on existing policies and laws or if higher goals in the development should be aspired. Especially the analysis of the requirements concerning the energy-efficiency aspects (see chapter 3.2) revealed that requirements derived out of laws and labels normally only address the use-phase of active products. But the manufacturing phase – also of active products – could possibly offer a high energy-efficiency potential as well, which could be addressed by the designer via special measures. A tool on the basis of laws and labels therefore would not consider all relevant aspects of energy-efficiency.
The energy-efficiency cluster-catalogue as the basis of a possible tool is realized at the moment in the form of excel-sheets. Therein for every country, products and their requirements derived out of laws and relevant labels are listed and unified, as well as specific calculation formula in dependence of product-/label-parameters are described. This catalogue needs continuous enhancement, so that energy-efficiency-requirements for a broad range of countries will be documented comprehensively in this tool. In a next step the catalogue needs to be enhanced by a user-interface that permits an automated activation of requirements, automatically generates a requirements list and moreover provides the designer with relevant information. With this tool practical tests have to be performed afterwards. In parallel a concept for an automated requirement extraction out of legal text has to be worked out, in order to minimize the effort to enhance the tool and keep the tool for the application in companies extendable and applicable.
As energy-efficiency is a topic of high importance, the concept of standardized requirement acquisition through clustering was in a first step applied to laws and labels in the field of energy, but could also be enhanced to other fields in order to further ease the elicitation of requirements for the designer.

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