Characteristics of Design Situations Influencing the Knowledge to Reuse

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This paper presents eleven characteristics of design situations which influence the type, the amount or the representation of the knowledge to be reused in a design situation. The proposed characteristics are the result of literature review and analysis. Based on our interpretations of the literature, we quantified the influence of each characteristic on each one of the aspects of the knowledge considered (type, amount and representation). No exclusive relation between one characteristic and one aspect of the knowledge could be found, but some tendencies could be identified and they are discussed.
In the second part of the paper, we present an approach for the practical use of the characteristics in order to support knowledge reuse during product design in industry. Based on this approach, the characteristics obtained from literature are discussed, modified, and measurement parameters for them are assigned. The paper closes with a plan to evaluate the feasibility of the proposed approach and the evaluation of the understanding of the final proposed characteristics by engineers.

1. Introduction

Not all knowledge that is available in a company is useful for reuse in all situations during the product design process. The adequate knowledge to be given to a designer in a design situation depends on several aspects like e.g. the design phase, the level of expertise of the designer or the available time.

Some approaches to support knowledge reuse have partially considered some of those aspects (Ahmed and Wallace 2004, Baxter et al. 2007, Chirumalla 2013). However, there has not been a full investigation on which are the characteristics of design situations which influence the knowledge that should be given to a designer for reuse in different design situations. As a consequence, current knowledge reuse systems are not able to provide the right knowledge when a search for knowledge is conducted. Thus, designers feel that recurring to knowledge reuse is more a waste of time than a useful activity, and the use of reuse systems decreases in the long-term run. As it has been concluded in studies conducted by Milton (2010) or the COVEO study of 2014, the effective reuse of knowledge in engineering companies is still a goal to achieve.

The objective of this paper is to define the characteristics of design situations which influence the knowledge to reuse in different situations. We considered three aspects of the knowledge which can be influenced: the knowledge type (tacit or explicit), the amount of knowledge and the knowledge representation.

2. Knowledge reuse

2.1 The Knowledge Reuse Cycle and the reusing stage

Two meanings for the term knowledge reuse can be found in literature. On one hand, knowledge reuse can be seen as one of the activities of knowledge management, referring to the specific moment in which individuals perform reuse. Fruchter and Demian (2002) distinguish two types of reuse: 1) internal reuse, which relays on own experiences and personal memories acting as knowledge repository; and 2) external reuse, which is the reuse of codified knowledge in form of documents stored in physical or electronic knowledge repositories.

On the other hand, knowledge reuse can be considered the whole process which is necessary in a company to end up reusing. Markus (2001) depicts this paradox presenting the Knowledge Reuse Cycle, which consists of four stages, and the last stage is called reusing. The stages of the Knowledge Reuse Cycle are the following: 1) capturing or documenting knowledge (generating documents); 2) packaging knowledge

(structured storage of the documents in a knowledge base); 3) distributing or disseminating knowledge (providing people access to documents); and 4) reusing knowledge (searching and applying documents). The Knowledge Reuse Cycle is meant for the reuse of external knowledge, i.e. codified knowledge.

2.2 Knowledge bases and knowledge search

A knowledge base is generally understood as a centralized repository for documents and a resource for the dissemination of knowledge. Current knowledge bases can be found in form of wikis, folders is a common server containing diverse files or integrated in intelligent software systems like PLM (Product Lifecycle Management) systems. The documents of a knowledge base are usually associated to metadata, which is information related to the document like the author or the creation date (Lauer, 2010). The metadata allows the structured search and distribution of documents, since it can be used in search engines coupled to the knowledge bases.

The most typical searching methods of reuse systems lean on key-words (pattern-matching), query searches (pattern-matching relying on relational structures), browsing (semantic search) or free search (the user selects the metadata by him/herself).

In the case of product design, the search of documents during the design process is initiated by the designer. He or she provides to the search engine the input to conduct the search. Depending on the method, this input will be a word, a query or metadata.

2.3 Finding the right knowledge

The aim of reuse systems is to provide designers with the right knowledge for reuse when they perform a search during their design work. But what is the meaning of "right"? We distinguish three aspects which define the suitability of the knowledge provided for reuse:

- Type of knowledge: it refers to the nature of the knowledge as being either explicit (i.e. contained in physical documents or digital files) or tacit (i.e available through personal interaction). In the case of tacit knowledge, the system cannot directly provide it, but it can provide the name of contact persons to exchange tacit knowledge.
- Amount of knowledge: it represents the number of documents or knowledge contacts that are suggested from a knowledge reuse system to reuse.
- Representation: it refers to the way of representation of the knowledge, which can be in texts, tables, 3D-models, diagrams or other kind of representations.

3. Research question and methodology

Applying the current search methods, receiving the right knowledge for reuse relies on the searcher ability to provide adequate search input. This is not an easy task for designers taking into account the uncertainty and changing dynamic of the design process. Improving the understanding of the characteristics of design situations influencing the knowledge to reuse, new search methods based on the changing design process could be developed. A design situation is understood as the moment during the design process in which a designer/s is/are working on a design activity.

The aim of this research work is to provide an answer to the following research question:

How can design situations be characterized in a way that supports the identification of the right type/amount/representation of knowledge to reuse in such situation?

The research approach is based on literature review and analysis and it is conducted in three steps, exposed in Figure 1.

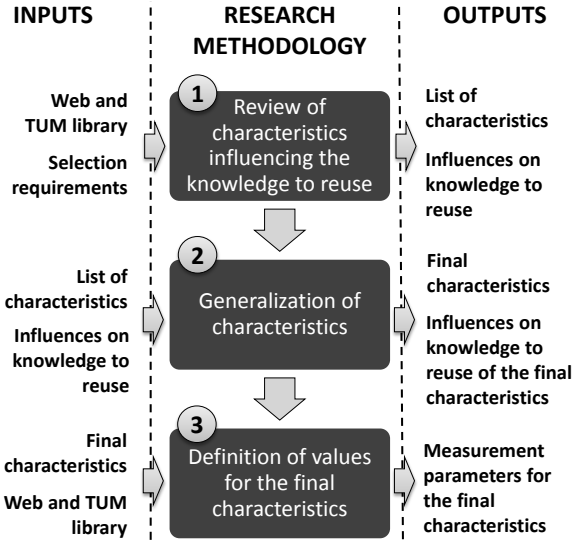

Figure 1. Research methodology.

The first step was conducting a literature review searching for evidence that some characteristics of design situations influence the type, amount or representation of the knowledge to reuse. Thus, we elaborated a list of statements from literature sources with the characteristics associated to the statements. The search engines used were Scopus, Web of Science, Google Scholar, and the university library. The results of the review are presented in section 4.1 of this paper.

The second step was the clustering and generalization of the collected characteristics in order to reduce their number and obtain the final characteristics of design situations influencing the knowledge to reuse. The final characteristics are presented in section 4.2 of this paper. Based on the output of step 1, we also identified the influence of each of the final characteristics on the aspects of the knowledge to reuse. These influences are presented in section 4.3 of this paper.

The third step of our research methodology was to provide values to measure the final characteristics of design situations. We looked for values which could fit

the approach for industrial application proposed in section 5.1. With the practical application in mind, we conducted a second literature review searching for ways of quantifying the final characteristics. The selected measurement parameters are presented in section 5.2 of this paper.

4. Characteristics of design situations

4.1 Review of the characteristics influencing the knowledge reuse

In our literature research we found 48 literature sources useful for the purpose of this investigation. The sources selected contained the word "knowledge" combined with "reuse", "sharing" or "transfer". All selected sources either investigated the phenomenon of knowledge reuse in engineering or proposed methods to support knowledge reuse in engineering design. For example, Busby (1999) conducts an investigation on problems to reuse knowledge in engineering design and Hao et al. (2013) propose a user-oriented design knowledge reuse model.

From the 48 sources we extracted 174 sentences with the correspondent characteristic influencing on knowledge reuse. Table 1 shows exemplarily three of the characteristics which were extracted from the statements. Those characteristics were things like being a novice designer, having innovation as design goal or the familiarity with the knowledge domain to reuse. We interpreted how the characteristic influences the knowledge to reuse based on the context of the original source and our own reasoning. Three aspects of the knowledge to provide for reuse in a design situation have been considered: 1) the type of knowledge (tacit or explicit); 2) the amount of knowledge; and 3) the knowledge representation.

From the statement of Ahmed and Wallace (2004) presented in Table 1 we see that novice designers are not able to select the important knowledge asset to reuse due to their lack of background. Our interpretation in terms of reusing knowledge is that low amounts of prioritize knowledge should be then provided to novice designers, so they do not invest time looking in large amounts of knowledge which they are not capable to prioritize. We derived this conclusion in line with the Ahmed and Wallace's work, who developed a methodology for novice designers to define concrete search questions which will lead them to less a more appropriate knowledge to reuse. Therefore, we established that the characteristic "novice" influences the amount of knowledge provided to reuse.

In the case of the statement found in Cheung et al. (2008), we considered that having innovation as design goal influences the type of knowledge (tacit or explicit) to be provided. This statement is quite clear about the relation since it explicitly suggest that tacit knowledge is the appropriate knowledge to reuse for the characteristic "innovation".

The statement of Boh (2008) claims based on her empirical study, that knowledge familiarity influences the ease of knowledge reuse. Boh's work suggests that personal contact (tacit knowledge) facilitates reuse in cases of low familiarity. Therefore, we assigned that the characteristic "familiarity" influences the type of knowledge. Boh (2008) also says that a shared perspective between the knowledge author and user facilitates the reuse. Our interpretation of this fact is that this common perspective can be achieved through personal contact or also through a common knowledge representation. Therefore, we also considered that the characteristic "familiarity" influences the knowledge representation.

Table 1. Three examples of the statements from literature to derive the characteristics influencing aspects of the knowledge to reuse.

Source	**Statement**	**Characte-ristic**	**Influence on knowledge to reuse**
Ahmed and Wallace (2004)	Novice designers were not observed to question data. They […] were not observed to differentiate between important and less important issues.	Novice	Amount
Cheung et al. (2008)	Innovation requires the transfer of largely tacit knowledge, which is hard to codify.	Innovation	Type
Boh (2008)	Individual familiarity with the (knowledge) domain were found to play an important role in affecting the ease with which individuals could reuse knowledge assets.	Familiarity	Type, representa-tion

Some of the characteristics extracted from our research have an influence on knowledge reuse but they do not influence the aspects of the knowledge to reuse (type, amount or representation) in a design situation. Those are characteristics such as organization culture, the technology (reuse system) or the company's infrastructure. Those characteristics influence the fact that knowledge reuse occurs but they are not relevant for our research question. Eliminating these types of

characteristics from the 174 characteristics collected from literature, we finally obtained a number of 110 characteristics relevant for our research question.

4.2 Generalization of the characteristics influencing the knowledge reuse

Most of the characteristics extracted from literature, were actually the way of characterizing a superordinate characteristic. For example, in the case of novice, the superordinate characteristic is the designer's "level of experience". In the case of innovation, the superordinate characteristic is the "purpose of reusing the knowledge". Table 2 shows some examples of the association between characteristics extracted from literature and the final characteristics.

Table 2. Three examples of characteristics extracted from literature statement which derived in a final characteristic of the design situation.

Characteristic from literature	**Final characteristic**
Adapt past solutions	Purpose of reusing the knowledge
Innovation	
Decision making	
Knowledge transfer	
Internal knowledge	Location of knowledge
External knowledge	
High distance	
Physical proximity	
Lack of time	Restriction on design time
Time	
Time pressure	
Search time	

Following this reasoning, we established the final characteristics of design situations influencing on the type, amount or representation of the knowledge to reuse in the situation. The final characteristics are:

- Level of experience
- Status in the company
- Type of group work
- Level of product complexity
- Level of familiarity with the product
- Design phase
- Type of activity
- Restriction on design time
- Location of knowledge
- Purpose of reusing the knowledge
- Stage to apply the reuse

Figure 2 shows the number of characteristics out of the initial 110 which were encompassed in each one of the final characteristics.

4.3 Influence of the characteristics on knowledge type, amount and representation

Based on the statements collected from the literature analysis presented in section 4.1, the influence of each

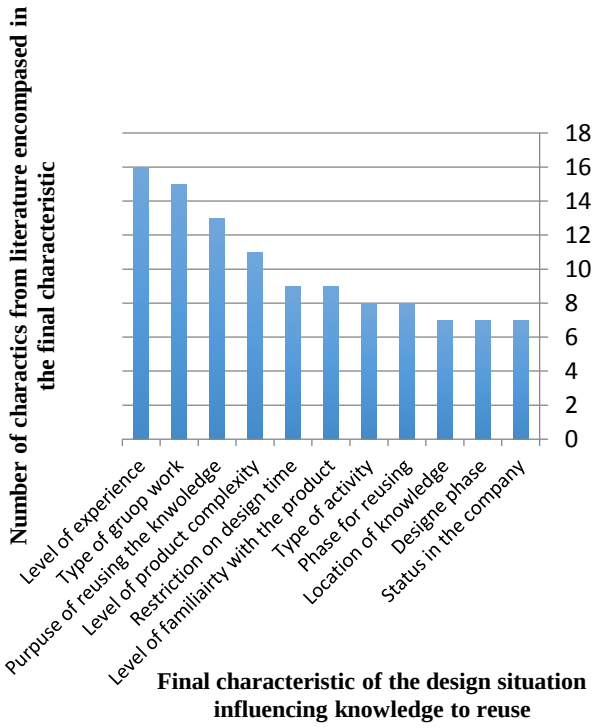

Figure 2. Number of initial characteristics encompassed in the final characteristic.

of the proposed characteristic on each aspect of the knowledge could be quantified. The influence derived from our data is represented Figure 3. In order to obtain the percentages, we first counted for each final characteristic, all the influences to the knowledge related to it. One influence is one association to one of the three aspects of the knowledge. For example, for the characteristic "level of familiarity with the product", we found 9 characteristics in literature (as it can be observed in Figure 2). From those 9 characteristics we had collected 12 influences on the aspects of the knowledge. The number of influences is higher than the number of initial characteristics because the characteristics extracted from literature could influence more than one aspect of the knowledge, as it is the case of "familiarity" in Table 1, which influences both knowledge type and knowledge representation. Then, we calculated the percentages of Figure 3 like follows:

$$\frac{\textit{Number of influences for the aspect of the knowledge}}{\textit{Total number of influences related to the final characteristic}}$$

Thus, continuing with the example of "level of product familiarity", we had that 5/12 (42%) influences on knowledge type, 2/12 (17%) influences on knowledge amount and 5/12 (42%) influences on knowledge representation.

Figure 3 shows that most characteristics influence most aspects of the knowledge. However, some light tendencies can be observed and some general recommendations have been identified during our investigation:

- The *type* of knowledge to provide in a design situation depends above all on the "status in the company" of the designer, the "restriction on the design time" and the "location of the knowledge". The "level experience" or the "design phase" do not seem to influence significantly the type of knowledge to reuse. Following relations have been observed:
    - Tacit knowledge is recommended in situations with high "restriction on design time".
    - Tacit knowledge is recommended in situations in which the knowledge owners are near.
- The *amount* of knowledge to provide in a design situation depends significantly on most characteristics. The "level of experience" of the designer, the "level of product complexity" and the "stage to apply the reuse" of knowledge can be especially highlighted. Following relations have been observed:
    - Low amount of knowledge is recommended in situations with novice designers.
    - High amount of knowledge is recommended for the beginning of a design situation.

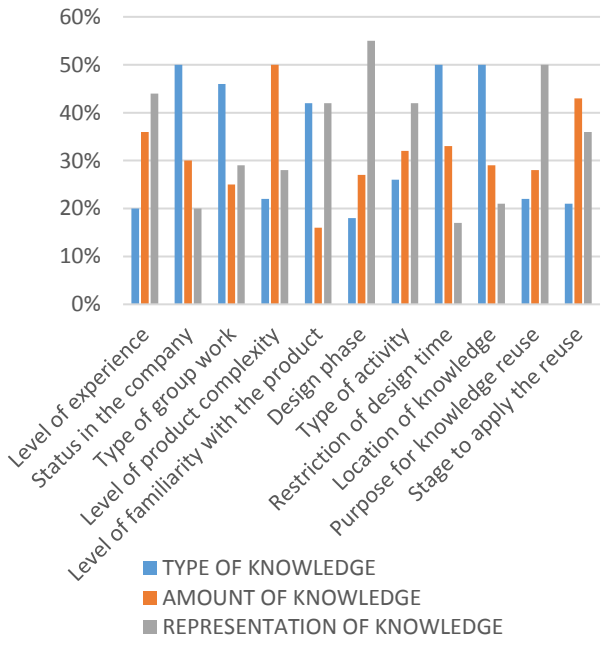

Figure 3. Identified percentage of influence of each characteristic on each aspect of the knowledge.

- The knowledge *representation* to provide in a design situation depends above all on the "design phase", the "level of experience" of the designer and the "purpose of reusing the knowledge". The "restriction on design time", the "location of the knowledge" and the "status in the company" do not seem to influence significantly the knowledge representation. Following relation has been observed:
    - Abstract knowledge representations (like working principles) are recommended for the phase of conceptual design.

5. Practical use of the characteristics

5.1 Theoretical approach for the industrial application

Characterizing the design situations with the proposed characteristics pursues two main goals:

1) *Facilitating the search for knowledge avoiding the formulation of search questions by the designer* - The characterization of the design situation by the designer is easy and it substitutes the formulation of a search question, which has been stated as a shortcoming for knowledge reuse (Ahmed and Wallace, 2004).
2) *Providing a base to identify the right type, amount and knowledge representation for reuse in a design situation* - We postulate the hypothesis that for the same situation (characterized by the same characteristics), the same documented knowledge may be useful to be reused (Carro Saavedra and Lindemann, 2015). We will refer to this hypothesis from now on as the "mapping hypothesis".

The practical use of the characteristics takes place during the design process. Then, designers working in different situations during the process, can proceed to characterize their situations and based on the characterization, knowledge to reuse from the company's knowledge base can be suggested. Figure 4 depicts the proposed approach.

In order to enable the mapping between design situations and knowledge, the documents of the knowledge base should be also characterized with some attributes (we assigned the word attributes to the characteristics of the knowledge contained in the knowledge base in order to avoid confusion with the characteristics of the design situations). The existence of patterns between the characteristics of design situations and the knowledge attributes is the claim behind the mapping hypothesis. Knowledge attributes can be among others the design phase in which a document was generated, the document size or the document author.

Two of the three aspects of the knowledge considered in the main research question of this paper can be also considered attributes of the knowledge contained in the knowledge base: knowledge type (tacit or explicit) and knowledge representation (text document, table, 3D model, etc.). However, the amount of knowledge to reuse in a situation is not an attribute of the knowledge but a variable associated to each specific mapping of design situation with knowledge to reuse.

As it could be observed in section 4.3., the rules to associate design situations to knowledge are unknown at the current state of research. Furthermore, the rules are probably not generalizable but they should be company-specific developed. Tracking successful cases of

knowledge reuse by designers in a company (i.e. collecting their design situation and the knowledge reused) during a period of time could be the way of deriving some replicable mapping rules.

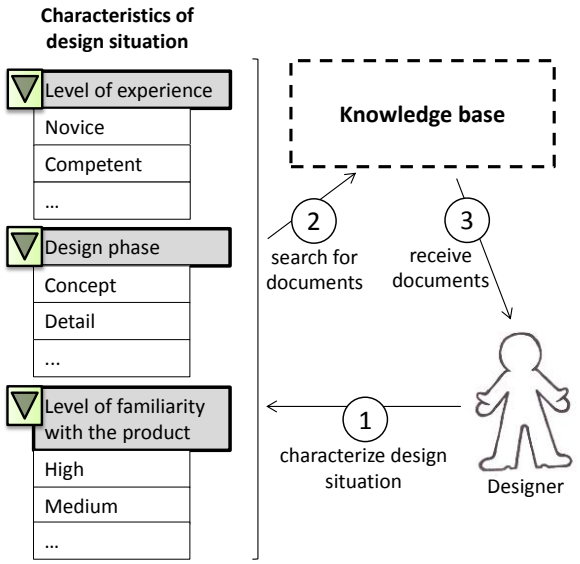

Figure 4. Approach for the practical application of the characteristics to support knowledge reuse during the design process.

Selecting the characteristics every time the designer wants to use the approach can be an annoying task for designers. In order to avoid the manual characterization, a computer-supported characterization could be applied. Those are some suggestions to provide the selection of the characteristics reducing the effort for the designer:

- For the characteristics "level of experience", "status in the company", "type of group work", "level of product complexity" and "level of familiarity with the product": one time input by designer at the beginning of a design project. Update if necessary. Automatic recognition of the characteristic through designer's computer account.
- For the characteristics "design phase" and "restriction on design time": automatic recognition of the characteristic through link with central project plan (e.g. Gantt Chart of the project).
- For the characteristics "type of activity", "purpose of reusing the knowledge" and "stage to apply the reuse": manual selection.

5.2 Characteristics and their measurement parameters for the industrial application

In order to use the characteristics as it is proposed in 5.1, clear definitions of the characteristics and the way of measuring them with measurement parameters should be established. It should also be considered if it is possible and easy for the designer to assign a measure for the characteristic. With this purpose, we conducted a new literature research to establish the definitions and appropriate way of measuring the characteristics for our purposes. In the following paragraphs we present the results for all the characteristics.

Level of experience: it is defined as the "level of familiarity with a skill or field of knowledge acquired over months or years of actual practice and which, presumably, has resulted in superior understanding or mastery" (Business Dictionary, 2017). Authors like Dorst and Reymen (2004) distinguish seven levels of expertise (novice, advance beginner, competent, proficient, expert, master and visionary). This way of measuring the level of experience is very detailed and we consider that it would be difficult for designers to select having so many options. Very often in literature level of experience is measured using three categories: expert, competent and novice. Those are the measurement parameters which we propose. The environment in which the knowledge base is going to be used should define the meaning of the parameters. It is not the same to apply it in a university or in an automobile company. In the first case the "level of experience" could be defined based on the number of specialized subjects coursed, while in the second case it could be defined as the number of projects in which the designer has been working.

Status in the company: it refers to the different positions employees can have in a development company. Based on our own experience, we classified the status in three:

- Project manager: responsible of the coordination of several teams.
- Team manager: responsible of the coordination of groups of people.
- Technical worker: responsible of performing technical tasks.

Type of group work: it is defined as "the type of interaction between workers" (Bertoni et al., 2011). Bertoni et al. (2011) define four types of interaction:

- Independent: partners do not interact in any form during their tasks and do not share information during the process.
- Communication: process of transferring information from one source to another but it does not imply working together on a common goal.
- Cooperation: association of a number of persons for their common benefit to pursue a common goal.
- Interdependent: tightly coupled way of working where people cannot be separated.

We propose those four types as measurement parameters for the characteristic "type of group work".

Level of product complexity: it is not easy to define product complexity, since it can be measured from different perspectives (design time, number of components, number of interfaces between components, etc.). A traditional way of defining the complexity of a product is by the number of structural components that are formally distinguished. This is our selected definition. The way of measuring it is subjective and different for every company depending on their reference products. We propose three measurement parameters: low, medium and high.

Level of familiarity with the product: it can be defined as the level of knowledge that the designer has with his/her current design before starting with it. The familiarity can be acquired from months or years of

professional practice or from hobbies and personal interests. We established four measurement parameters:

- None: no subject, hobbies or professional experience related to the product.
- Low: hobbies or subjects related.
- Medium: hobbies and subjects related.
- High: professional experience.

Design phase: it represents the phase of the design process which is being conducted. In order to define the design phases, we refer to the four main phases defined by Pahl and Beitz (1996):

- Product planning: the clear aims, constraints and criteria of the engineering problem are determined. At the end of this phase the requirements and constraints are compiled.
- Conceptual design phase: identification of the essential problem, establishment of the functional structures, search of principle solutions and evaluation of concept variants.
- Embodiment design: development a definite layout and check that the requirements are met. Clarify, confirmed and optimise many details.
- Detailed design: specification of different characteristics (dimensions and tolerances, material and surface properties…) and production of all the drawings and production documentations.

Type of activity: it refers to the type of individual task the user is undertaking in their design. Sim and Duffy (2003) identified three main types of activities in the design process (design definition activities, design evaluation activities and design management activities). For each activity type they define almost ten sub activities. Those may be too many for a designer to clearly identify their differences and be able to select with which is he or she proceeding in a design situation. In order to simplify the selection, we chose as measurement parameters for "type of activity" the following activities defined by Eggersmann et al. (2003):

- Synthesis: activities to pit together ideas into new or unique products. They are associated with design objects like functional or mathematical models.
- Analysis: activities to break down a problem into smaller parts. They generate data about the design. It is normally used to simulate behaviour and to predict its performance.
- Decision: make a selection from all the available options. It is decided if the design object is selected, rejected or kept in mind as a possible alternative.

Restriction on design time: it is defined as the time the designer has to finish the design phase in which he or she is. Three measurement parameters are considered:

- Low: the available time is enough to conclude the design phase as it was planned working in normal speed.
- Medium: the available time is enough to conclude the design phase as it was planned working faster than usual.
- High: the available time is probably not enough to conclude the design phase as it was planned.

The way of measuring "restriction on design time" is subjective and different for every company or person.

Location of knowledge: this characteristic does not seem possible to be selected by the designer when characterizing the design situation because the required knowledge for reuse is still unknown and so it is its location. The location of knowledge as it being internal to the company or external, far or close from the knowledge user is appropriate as attribute of the knowledge, but not as characteristic to select in the situation. This characteristic is not further considered because it does not match the approach for the practical use of the characteristics of the design situations.

Purpose of reusing the knowledge: it can be defined as the overall design purpose for which the user wants to reuse knowledge from the knowledge base. This characteristic can be confused with "type of activity" but this one refers to a design goal on a more abstract level. The concept can be understood with its measurement parameters, based on Majchrak et al. (2004), who defined two purposes:

- Replication: copying or reproducing exactly assets and resources that embed organizational knowledge.
- Innovation: adapt existing knowledge to accomplish an innovative task.

Stage to apply the reuse: it represents the moment of the design phase in which knowledge is reused. It is associated to the concrete purpose of reuse. There are three possible stages defined by Schacht and Maedche (2016):

- Preparation: knowledge reuse takes place at the beginning of the design phase in order to search for information to be aware of possible failures and points to be considered.
- Recapitulation: knowledge reuse takes place in the middle of the design phase, when the designer has a concrete problem or when he does not know how to continue.
- Cope with the past: knowledge reuse takes place at the end of a design phase and it serves to confirm the current result by comparison with previous results.

Personality: this characteristic was not obtained as a result of the research presented in section 4 of this paper. However, we would like to introduce it as a characteristic of the design situation. It is a characteristic directly related to the designer as it is "level of experience" or "status in the company", and we believe that it may also influence the knowledge to reuse. From our point of view, one of the main shortcomings of the up to date state of research on supporting knowledge reuse is the lack of consideration of designers' needs and behaviours (Carro Saavedra et al., 2015). Therefore, we decided to add the characteristic "personality" to the characteristics that we could derive from our literature research. "Personality" is defined as "the totally of an individual's behavioural and emotional characteristics" (Merriam Webster, 2017). For the definition of designer's personality, we propose the Myers-Briggs Type Indicator (MBTI) (Myers et al. 1998). It is an introspective self-report questionnaire designed to indicate psychological preferences in how people perceive the world and make decisions. These

preferences are based on how people focus their attention or get their energy (extraversion or introversion), how they perceive new information (sensation or intuition), how they take decisions (thinking or feeling) and how they orient themselves towards the outside world (judging or perceiving).

All proposed characteristics for practical use and their measurement parameters are summarized in Table 3.

Table 3. Proposed characteristics and measurement parameters for their practical application.

Characteristic	Measurement parameters
Level of experience	Novice
	Competent
	Expert
Status in the company	Project manager
	Team manager
	Technical worker
Type of group work	Independent
	Communication
	Cooperation
	Interdependent
Level of product complexity	Low
	Medium
	High
Level of familiarity with the product	None
	Low
	Medium
	High
Design phase	Product planning
	Conceptual design
	Embodiment design
	Detailed design
Type of activity	Synthesis
	Analysis
	Decision
Restriction on design time	Low
	Medium
	High
Purpose of reusing the knowledge	Replication
	Innovation
Stage to apply the reuse	Preparation
	Recapitulation
	Cope with the past
Personality	Extraversion or introversion
	Sensation or intuition
	Thinking or feeling
	Judging or perceiving

6. Evaluation of the characteristics

6.1 Evaluation plan for the mapping hypothesis

The mapping hypothesis proposes that there is a relation between the design situation and the knowledge to reuse. That means, for the same design situation (characterized by the same characteristics), the same documented knowledge (same amount, type, representation and other attributes) may be useful to be reused.

In order to test the hypothesis, we propose to conduct design workshops, in which the participants perform a product design. Two types of workshops are necessary:

- Workshop type 1: the participants conduct a product design and they receive a knowledge base which they can use during the design process. They can freely explore the knowledge base. Every time one participant uses knowledge from the knowledge base, he or she is asked to characterize his or her design situation. The goal of the workshops type 1 is to create the first association of knowledge to design situations.
- Workshop type 2: the participants conduct a product design and they receive a knowledge base which they can use during the design process. They cannot see the content of the knowledge base. If they want to access the knowledge, they must characterize their design situation. The participants will receive knowledge which has been useful in similar situations during workshops type 1. Then, the usefulness of the knowledge received will be evaluated. The goal of the workshops type 2 is to provide the first indications of the validity of the mapping hypothesis.

The product to design in both types of workshops must be different in order to avoid that the usefulness of the knowledge received in workshops type 2 is just a consequence of designing the same product. The usefulness of the knowledge reived should arise from the generalization of knowledge from different projects to support a new design.

Those workshops do not take place in an industrial context and therefore, the characteristics “status in the company” and “type of group work” cannot be considered. The characteristic “personality” is not selected by designers, but measured using the Myers-Briggs Type Indicator (MBTI) (Myers et al., 1998). Thus, 8 characteristics of design situations remain for the workshops to be selected. Those 8 characteristics can be divided in two groups:

1) Non-variable characteristics: they remain constant during all the design workshop. They have to be characterized only once. Those characteristics are: “level of experience”, “level of product complexity”, “level of familiarity with the product”.
2) Variable characteristics: they vary during the design workshop. They have to be characterized every time the approach is applied. Those characteristics are: “design phase”, “type of activity”, “restriction on design time”, “purpose of reusing knowledge” and “stage to apply the reuse”.

6.2 Evaluation of the understanding of the characteristics and their value parameters

One key aspect to proceed with the evaluation plan is the good understanding of the characteristics and their value

parameters by engineers. Engineers must be able to characterize their design situations without doubts. The evaluations of the level of understanding of the characteristics and their value parameters took place with a questionnaire. The participants were 11 industrial engineers from Spanish (6) and German universities (5) with an average age of 25 years old.

The questionnaire had both close and open questions. We asked only about the 8 characteristics which will be selected during the workshops proposed in 6.1, because they are the ones which engineers would have to select on their own. For each characteristic, we asked about three aspects: 1) the understanding of the definition; 2) the understanding of the way of measuring it; and 3) the feasibility of choosing a value for it.

The results of the questionnaire were very positive. For most of the characteristics, all participants (100%) answered positively for the 3 categories asked. There were only three negative answers on the following questions: 1) understanding of the definition of "stage to apply the reuse", 2) feasibility of choosing a value for "level of experience" and 3) feasibility of choosing a value for "restriction on design time".

The participants who provided the negative answers were contacted in order to discuss with them their doubts. In two of the three cases the reason for the negative answer was that the participant was reluctant to answer yes to all the questions, even though he or she had understood the characteristic and the way of measuring it. The remained negative answer was related to the measurement parameters of the characteristic "restriction of design time". The participant considered that the time ranges proposed were very short for a product design. This was because adjusted the values to the workshops length (hours) and he had not understand it this way.

7. Discussion

This paper contributes to the research community providing a list of eleven characteristics of design situations influencing the knowledge to reuse during the design of a product. The characteristics were derived from the analysis and synthesis of literature sources. One limitation of the investigations is its subjectivity. Almost none literature source named explicitly the influences which we were looking for. In order to obtain results for our research question, we identified statements in which we could interpret a certain connection, and so the results are subject to our interpretation. This applies also for clustering of the initial characteristics to derive the superordinate characteristics.

The existence of an influence of the eleven characteristics exposed in section 4.2 on the knowledge to reuse seems clear. However, direct correlations between their values and the knowledge could not be determined in this investigation. Just a few recommendations like "tacit knowledge is recommended in situations with high restriction on design time" could be established. The problem is multifactorial and it should be company- and designer-individually addressed.

This work contributes to the industrial practice by proposing an approach to support knowledge reuse based on the identified characteristics of design situations. The feasibility of the approach is based on the validity of the mapping hypothesis, which claims that the same knowledge (characterized by the same attributes) can be associated with the same design situations (characterized by the same characteristics). The realization of design workshops with different products to design is proposed to test the hypothesis. There are two big challenges regarding those workshops. First, defining how should product designs proposed in different workshops differ from each other in order to allow a beneficial knowledge reuse which is not a consequence of the similarity of the products to be designed. Second, determining how many workshop should be conducted to obtain enough data to find patterns between design situations and knowledge.

The approach for industrial application is realistic only if activities like the characterization of the design situation can be automatically supported. Even a (semi)-automatic implementation can be a huge challenge for the companies in terms of adaptation of their software and documents. Also, the adequate frequency for characterization remains an open question.

Finally, we would like to point out that the problematic for knowledge reuse in development companies is not only related to the problematic of finding the right knowledge. There are numerous factors influencing at a company level like infrastructure, culture, trust or motivation. They must be also considered to achieve efficient and continuous knowledge reuse.

8. Further work

Our next step is to conduct the experiments presented in section 6.1 to validate the mapping hypothesis in design workshops. If the mapping hypothesis can be validated in experiments, the next step is to prepare the industrial application of the characteristics for the purpose of supporting knowledge reuse. One aspect to investigate is the feasibility of a passive (computer-aided) acquisition of the characteristics of the design situation during design work, so designers do not have to define the characteristics themselves and receive suggestions for knowledge to reuse automatically. Furthermore, we suggest for the industrial implementation, deriving the patterns to link the knowledge to the design situations using artificial intelligence methods (e.g. artificial neural networks) based on the tracking of the designers choices of knowledge for reuse. How to implement such method should be also investigated.

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