INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

TAXONOMY FOR UNDERSTANDING KNOWLEDGE CAPTURED IN DOCUMENTS BY DESIGNERS

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ABSTRACT
In this competitive scenario of product development, product success is substantially influenced by satisfaction of the knowledge needs of designers. In literature many tools and methods are proposed to support satisfaction of these needs. But, adoption of these methods in industrial set-ups is minimal. This may be due to an inadequate understanding of the knowledge needs of designers in an industrial set-up. This research attempts to bridge this gap by undertaking a descriptive study in an industry. The research question we address in this paper is "what knowledge is captured in formal documents?" In order to answer the question, we converted the content of formal documents into potential questions which they answer. We propose a taxonomy of knowledge on the basis of analyzing the questions generated from formal documents. Since the analysing the above questions using elements within each independent category in the taxonomy will lead only to a partial understanding of the knowledge captured, we converted each question into a generic form with the help of the taxonomy. These questions are aimed at providing an understanding about: (i) relationships between the elements in the taxonomy and (ii) the underlying structure of the knowledge. We argue that this taxonomy and generic questions should aid in a better understanding of the knowledge captured by designers.

Keywords: Taxonomy, Knowledge, Documents, Questions

1 INTRODUCTION
In this globalizing world, companies are facing stringent requirements from their customers in the form of more innovation, reduced cost, high quality and less time to develop products. Industry needs to satisfy these requirements, with the reality of product development personnel frequently changing jobs. To compete in the current design scenario, companies must start to enhance the reuse of internal and external engineering knowledge, concentrate on core competence by making maximum use of components and services available on the world market, form virtual enterprise with firms who focus on complementary core competence, and change the engineering culture by replacing previous competition by new forms of co-operation.

In order to retain their core competence, the knowledge developed in the product development process should be captured, structured and made available for reuse across its projects and units. It has been shown that 70 to 95% of the design work could consist of reusing, configuring, and assembling of existing components, solutions and knowledge [1]. The immense potential of capturing the necessary knowledge developed in the design process is that it aids in redesign or design of similar products, communication between designers and others, understanding previous designs, explanation of the design process, training of novice designers, and avoidance of 'reinventing the wheel'.

In literature many knowledge reuse approaches, representations, and capture and retrieval methods are proposed. But adoption of these methods and tools in an industrial set-up is minimal. A possible reason for this status is that the knowledge needs of designers and industries are not appropriately understood and addressed. This research attempts to bridge this gap by undertaking a descriptive study in an industry in order to understand the knowledge needs of the designers during the product development process.

The subsequent discussions in this paper are organized into six sections. Section 2 provides a detailed literature survey about knowledge processing and the relevance of this paper. Section 3 elaborates the model of knowledge processing proposed in this paper, and a set of research questions framed from that model. Section 4 discusses the approach followed to answer the research question framed. Section

5 proposes the taxonomy of knowledge observed from the analysis of questions. Section 6 elaborates, as an example, a generic question framed using the taxonomy. Section 7 presents conclusions from these observations and future work to be carried out.

2 LITERATURE SURVEY

In this section we detail the need for understanding knowledge processing activities, and the challenges and kinds of knowledge representation.

2.1 Need to understand knowledge processing activities

Frankenberger & Badke-Schaub [2] argue that availability of information is a central factor for the success of a design. Marsh [3] observes that designers spend on an average 24% of their time in information acquisition and dissemination, and majority of this information is obtained from personal contacts rather than formal sources. Crabtree et al. [4] point out that project delays are mainly due to time spent in information acquisition and information access. The associated delays range from a single day to a year. MacGregor et al. [5] observe that engineers use company systems and colleagues in the same office to get information, and engineers perceive that 34% of their time is taken in sourcing and locating for relevant information. Ottosson [6] estimates that less than 20% of the information that we get is used in building up new pictures of the world while the remaining part comes from our earlier pictures stored in the brain. Busby [7] found that engineers often failed to learn from their experiences because the feedback provided to engineers from previous projects was often unreliable, delayed and negative, and sometimes missing altogether. Frank [8] argues that knowledge management verges on creativity when knowledge and experience are transferred from one field of activity to another. Stewart [9] claims that only 20% of a firm's knowledge is effectively used by today's organizations.

2.2 Benefits of knowledge representation

The usefulness of the information that is captured in a design history depends on how it is indexed. Werner and Ahmed [10] argue that documentation and design process information must be well organised to facilitate automatic processing and search operations. Gregory et al. [11] show that the cost of interoperability barriers of IT systems used in engineering and manufacturing in the US auto industry is estimated to be of the order of $1 billion per year. Good knowledge representation schema to a great extent will influence to solve interoperability issues. Kneebone and Blount [12] argue that development of standards for knowledge representation will be one of the mechanisms by which knowledge sharing and re-use might be achieved.

2.3 What is knowledge representation?

The answer to this question is best given by Davis et al. [13] who argue that knowledge representation can be understood in terms of five distinct roles it plays, each crucial to the task at hand:

- A knowledge representation is most fundamentally a surrogate, a substitute for the thing itself, used to enable an entity to determine consequences by thinking rather than acting, i.e., by reasoning about the world rather than taking action in it.
- It is a set of ontological commitments, i.e., an answer to the question: In what terms should I think about the world?
- It is a fragmentary theory of intelligent reasoning, expressed in terms of three components: (i) the representation's fundamental conception of intelligent reasoning; (ii) the set of inferences the representation sanctions; and (iii) the set of inferences it recommends.
- It is a medium for pragmatically efficient computation, i.e., the computational environment in which thinking is accomplished. One contribution to this pragmatic efficiency is supplied by the guidance a representation provides for organizing information so as to facilitate making the recommended inferences.
- It is a medium of human expression, i.e., a language in which we say things about the world.

2.4 Kinds of knowledge representation

This section discusses various approaches, models and representations relevant to this paper. The differences between knowledge management generations are illustrated by Stenmark [14], Hansen et al. [15], McMahon et al. [16] and Regli et al. [17]. i.e., the distinction between a commodity view or codification strategy or feature-oriented approach (standardized products), and a community view or personalization strategy or process-oriented approach (customized solutions). The process-oriented approach to design rationale helps designers by providing descriptive history information, to answer questions such as who, why, what and when. Currently, it is not easy to translate this into representations that can be understood and processed by computers, so this approach provides support to the design process only when designers access and understand it [18].

While the feature-oriented design rationale approach provides active support to design activities, it has the limitation that only a part of design rationale (i.e. how the artifact designed satisfies the requirements) can be handled: other parts (i.e. option-exploration, trade-off, who, when, why, etc.) cannot be handled with this approach [19]. Combinations of both of these approaches have been proposed to help overcome their individual limitations. Systems with such a hybrid approach not only provide a logical structure for design rationale, but also record the history of the design process. KBDS-IBIS is one such example [20].

Venselaar [21] distinguishes knowledge into domain specific and general knowledge, each of these types of knowledge is classified further into four different sub-types: *declarative knowledge, procedural knowledge, situational knowledge and strategic knowledge.* Desouza et al. [22] categorize knowledge generated by projects as knowledge in projects (schedules, milestones, meeting minutes and training manuals), knowledge about projects (when, what, how, where, and why something is being done and why), and knowledge from projects (post hoc analysis and audit of key insights generated from carrying out projects).

Duffy et al. [23] propose a design reuse model which consists of processes for: design by reuse, domain exploration and design for reuse, and six knowledge-related components: design requirements, sources of domain knowledge, reuse library, domain model, evolved design model and completed design model. They argue that other reviewed models were either highly dependant on the individual system/approach, or alternatively were paradigms of Case Based Reasoning (CBR). CBR is a research interest in the field of 'design re-use', however, the assumption of the existence of a large base of past design cases, the applicability of cases in their entirety, and its limited focus on mainly representation and recall issues, negate this as a comprehensive model of re-use.

Werner and Ahmed [10] present Ligo, a design support system which combines the efficiency of on-line capturing and the automatic processing capability of formalised design units. Design objects contain a behaviour description and interfaces, to allow them to be used as independent building blocks. Ligo organises information in network of relations, called a 'semantic web'. Examples of relations are 'is special case of', 'is caused by', 'is realised by', etc.

Garza [24] discusses a design rationale system, a path-finder computer program called Design Rationale for the Information phase of Value Engineering. It consists of two modules: a domain-dependent Knowledge Representation Module (KRM), which contains objects and attributes representing building design information, and a domain-independent Rationale Storage Module (RSM), which contains all the design decisions made about the different performance parameters of various design objects in the KRM. The *depends-on* and *has-relationship* semantic net links of RSM generates a Parameter Dependency Network, which can determine how the designers arrived at a particular design decision. It can also determine how one object-parameter affects other object-parameters and further affects other object-parameters.

Smith and Duffy [25] argue that knowledge from the earlier stages of design (function, behaviour, solution concepts) and the 'how' and 'why' (rationale) of a designed artefact are key elements to the re-use approach.

Malmqvist [26] describes an approach based on an extended version of the function-means tree model of the design process and the chromosome model for product modelling to concurrently document the reasons for the design decisions made and the reasoning process that led to the final result. Hubka and Eder [27] describe a technical system and the transformation process that affects it in terms of process, function, organ and component structures. In a design process context, it is also necessary to have a model that states the design specification. The specification and the structures are linked by causal relations: the process determines the functions, the functions are created by the organs, and the organs are materialized by the components (Andreasen [28]). These relations constitute the genetic information of the system and can, hence, be used to describe its design history.

Malmqvist [26] argues that the chromosome model is neither very practical as a synthesis tool nor for describing the overall design process of a product (although much of the necessary information is included): The co-evolution of function and form during the design process is not made clear and it is difficult to visualize alternative solutions. Based on the general problem-solving process (Suh [29]) and overall design process model (Andreasen [28]) he argues that only on this level there is some empirical evidence that this is a reasoning pattern followed by practicing designers. It is therefore his opinion that design history tools should be targeted at this level. The extended function means tree model contains *functional requirement*, *means*, *objective* and *constraint objects*, and *solved by*, *alterative solutions* and r*equirements on* and *has influence on* relations. He argues that given these specifications, the function-means tree model becomes a simple yet powerful tool for design history representation, capable of representing the basic types of design history information listed by Ullman [30].

Szykman et al. [31] represent product knowledge as *requirements*, *specifications*, *artefact (sub-artefacts, functions [sub function, input & output flows], form [geometry {sub geometries, features}, materials], behaviours), design rationale, constraints and relationships*. Taura and Kubota [32] build a database, called an 'engineering history base', from which engineers can retrieve explanations to enable reuse of product information. They argue that explanation from the 'process' viewpoint is important in promoting reuse of product information. Process information is modelled using a Process Unit. A Process Unit is comprised of five elements: *action*, *object*, *alternative*, *constraint* and *reason*. Product information is modelled using three classes: *product class*, *data File class* and *attribute class*. The integration of product information and process information is achieved by product information playing the role of vocabulary for describing process information.

Brissaud and Poveda [33] propose a descriptive model based on features capitalising on the rationale of a design: a *conjecture* (an element of a solution proposed for validation), a *criterion* (an element of evaluation of the proposal) and the *interactions* between them to enable the system to capture design process rationale. Conjectures capture alternatives; criteria provide access to the rationale behind the alternatives. Kruger [34] describes analysis in conceptual design by the following activities: *select information {choose, justify, ask, confirm, obtain and classify}, verify information {ask, obtain and compare}, identify relevant facts, explicit and implicit constraints, establish a working model {obtain, establish and activate}, define requirements {weigh, choose and operationalize}.*

Kuffer and Ullman [35] define design history as a representation of the evolution of a product from its initial specifications. They argue that in order to develop a usable design history, it is necessary to determine the types of information needed by designers when they attempt to understand a design. Taxonomy of questions asked by designers includes *category, topic, age of topic, nature, confirmation, and validity*. A significant finding was that 51% of the questions and conjectures were about old topics, and a high percentage of questions and conjectures were about the construction of features and components.

Steiner [36] proceeds to use interrogative pronouns to distinguish between different kinds of questions. Given the different interrogative terms, the following kinds of quantitative research questions can be distinguished: who, where, when, how, why, which, and whether.

Gruber and Russell [37, 38] propose an approach for acquiring justifications by transforming why-questions into what-questions. It changes the open-ended task of explaining *why* into the constrained task of selecting *what* is relevant. They transformed extracted segments of protocols into a generic question using a limited vocabulary of abstract terminology. The vocabulary used were *behaviour, constraint, constraint model, decision dependency model, design alternative, design criteria, design parameter, environmental parameter, functional requirement, functional parameter, part, parameter, requirements, requirement constraint, scenario of use, specification,* and *structure*.

Following the procedure, they analyzed all the protocols collected, and produced a set of 63 generic questions. Each generic question represents a kind of information need or use, and a potential opportunity for computational support. The questions are grouped into 14 question classes by topics. These are: *requirements, structure/form, behaviour/operation, functions, hypothetical, dependencies, constraint checking, decisions, justifications and evaluation of alternatives, justifications and explanations of functions, validation explanations, computations on existing model, definitions* and *other design moves*. This list of questions is possibly incomplete, yet represents a fairly large space of design information. Table 1 illustrates various knowledge representation schemes found from literature.

2.5 Challenges in knowledge representation

Some of the barriers impeding the realization of the overall concept of knowledge re-use and sharing addressed in Neches et al. [39] were:

- There is a host of knowledge representation schemes that can be adopted in developing a knowledge base.
- Within a single knowledge representation scheme there are a number of dialects in which they could be implemented.
- The lack of shared sets of explicitly defined terminology, as to how knowledge is described and structured.

Duffy and Legler [40] argue that though simple approaches to reuse can be taken, the volume of data involved, and the complexity of interaction of relationships implicit in data lead to the need for supporting methodologies, techniques and tools. Ullman [30] argues that design re-use process model should consider re-use as a total process which, with the support of well-developed tools and methods, can encompass all phases of the design life cycle. Grabowski and Rude [41] argue that the common solutions for migration and retrieval of information are simply overtaxed because of the lack of semantics. They suggest that the use of ontology technology will be the key to overcome the named shortcomings by means of enabling network-wide information management at higher semantic levels.

2.6 Summary of literature survey

On average, designers spend 30% of their working time in knowledge acquisition and dissipation during design. The efficacy of designers will be improved significantly if knowledge generated during the design process is appropriately organized for later use. Only some of the knowledge representation schemes are intended to understand the knowledge needs of designers. Other schemes attempt only to map the design space. An important point to note is that most of the descriptive schemes were proposed from data collected under laboratory settings. Knowledge needs of designers in industry are yet to be comprehensively observed and identified. Also, the difference in knowledge needs of designers between different stages of the design process is yet to be studied. An exhaustive representation of product and process knowledge is still missing in current literature. Also, dependencies between product and process knowledge are not adequately identified. The subsequent sections address some of the issues found from this literature survey.

3 KNOWLEDGE PROCESSING MODEL & RESEARCH QUESTIONS

In order to understand the knowledge reuse spectrum, it is necessary to study what knowledge is produced and captured during the design process. Figure 1 shows the knowledge processing activities.

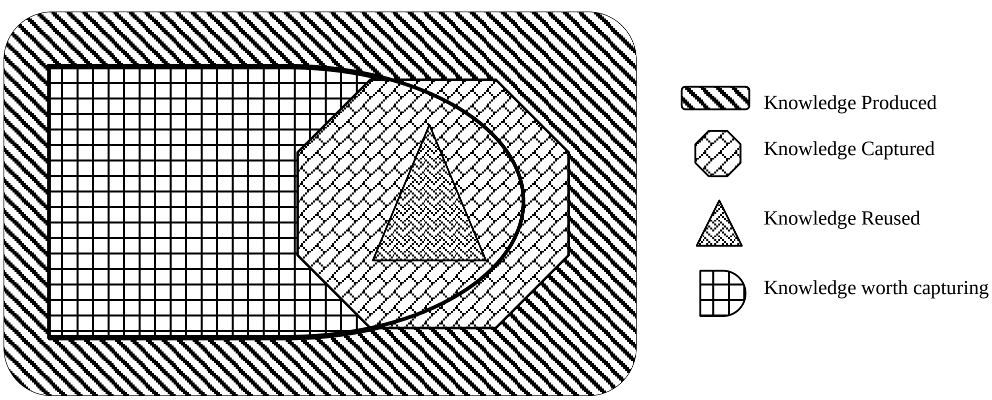

Figure 1. Knowledge processing model

From Figure 1, the following research questions have been framed;

1. What knowledge is produced during product development processes?
2. What portion of it is currently captured?
3. What portion of it is currently reused?
4. What knowledge is developed but not captured that should be otherwise?

In this paper we address the second question. This question is worth answering because currently majority of the information is obtained from personal contacts rather than formal sources [3] and understanding of knowledge needs of designers in design process is inadequate in an industrial context. The question is interpreted as 'What knowledge is captured in formal documents?' This is because knowledge is currently captured in an organization in formal documents only. Formal documents are reviewed and revised by formal committees in industry and are given unique identification numbers for reference.

Table 1. Kinds of knowledge representation

Author(s)	Knowledge Representation	Categories
Kunz and Rittel [42]	Issue Based Information System (IBIS)	Issue, Proposal and Argument; and 8 types of relationships among them
Potts and Burns [43]	Potts and Burns Method	Issue, Alternative, Justification and design artefact; and user derives the relationship between categories
McCall [44]	Procedural Hierarchy of Issues (PHI)	Extends IBIS by broadening the scope of the concept 'issue' and by altering the structure that relates issues, answers and arguments.
McLean et al. [45]	Question, Option and Criteria (QOC)	Question, Option and Criteria; and several predefined relationships between the categories
de la Garza and Ramakrishnan [46]	Design Rationale Authoring and Retrieval System (DRARS)	It is a variation of QOC. Views, goals, alternatives, claims, questions, answers and versions are the DRARS system's objects.
Lee and Lai [47]	Decision Rationale Language (DRL)	Issue, Alternative, Claim, Goal, Question, Procedure and Artefact; and several predefined relationships between the categories
Chandrasekaran et al. [19]	Functional Representation (FR)	A representational scheme describes how the device works (or is intended to work).
Goel A. [48]	Structure, Behaviour and Function (SBF)	Explicitly represents the functions of the device (the problem), the structure of the device (the solution) and the internal causal behaviours of the device.
Rosenman and Gero [49]	Purpose, function, behaviour and structure	Structure exhibits behaviour effects function enables purpose: or, purpose enabled-by function achieved-by behaviour exhibited-by structure.
Blessing [50]	PROSUS	Predefined categories in the form of matrices to capture the generation, evaluation and selection processes in design
Nagy et al. [51]	Object-Relation-Object) OREO	Issue, Proposal, Argument, Constraint, Decision and Design Object; and several types of predefined relationships between the categories.
Ramesh and Dhar [52]	Representation and Maintenance of Process knowledge (REMAP)	Issues, Positions, Arguments, Assumption, Requirement, Decision, Constraint and design object; and several types of predefined relationships between the categories.
Nidamarthi [53]	Phase, Primary level and Secondary level activities	Problem understanding (Identify, Analyze, Choose) and Problem solving (Generate, Evaluate, Select)
Chakrabarti et al. [54]	SAPPhIRE model	State, Action, Part, Phenomenon, Input, Organ, Effect and Relationships

4 APPROACH

To answer the four research questions, we undertook a series of case studies in a product development organization. In order to answer the second question (the focus of this paper), we converted the content of formal documents into potential questions which they answer. This approach raises the following question: how do you know what questions are appropriate to represent the content of a document? The goal is therefore to develop a structure of the questions that would typify the kind of knowledge captured by designers. This requires development of a taxonomy of knowledge, and is developed by analyzing the structure of questions from earlier research, using literature that analyzed knowledge needs of designers and taxonomies of design knowledge proposed by existing literature.

5 TAXONOMY OF KNOWLEDGE

With the approach mentioned in the previous section, we have generated 503 and 82 questions from two design documents. The documents were generated for a redesign task that involved an FEM analysis of a filter component. The content of the documents were clearly presented and intelligible. Since neither of the classifications discussed in the literature survey section provide an adequate insight into the knowledge needs of the designers, we propose a new taxonomy of knowledge needs of designers. This is based on literature and other observations at study. The rationale for the proposed taxonomy is to integrate the various models, approaches and representations proposed to structure the deliberation or argumentation made during product development process, artefact being designed, problem solving strategies and the design process itself. The argument is that without integrating these four purposes the value of the representations would not be that beneficial to answer the four questions generated from the knowledge processing model (Figure 1). Thus the proposed taxonomy integrates the factors representing these purposes.

The taxonomy has four broad categories of knowledge. These are: topics, classes, activities and types of questions. The groups in each category are detailed in Table 2. The elements in each group under each category are mutually exclusive. Chakrabarti et al. [55] argue that glossary is important for engineering design research because it will foster an unambiguous communication among the research community. To emphasize their argument, the terms used in this taxonomy are defined with examples in Appendix 1.

Table 2. Taxonomy of Knowledge

Categories	Factors
Topics	Issues and Proposals; Information and Knowledge; New and Old;
Classes	Product-based and Process-based; Requirement, Requirement-Problem, Solution, Solution-Problem, and Requirement-Solution; Function, Structure and Behaviour; Property, Value, Material, Assembly, Component, Interface, Environment, Method, Feature, Manufacturing and Location;
Activities	Problem understanding and Problem solving; Generate, Evaluate and Select;
Types of questions	Descriptive (answer is elaborate) and Point (answer can be yes or no; right or wrong).

The knowledge captured in the documents by designers by analyzing the 585 questions using the taxonomy are:

In topics,

- The questions related to proposals (93%) considered for the particular task are higher compared to the issues (7%).
- Information related questions (92%) are higher compared to knowledge related questions (8%).
- All the questions analysed are categorised as old question.

In classes,

- Process-related questions (58%) are more than product-related questions (42%).

- Solution-related questions (34%) are higher compared to requirement (9%), requirement-solution (6%), solution-problem (7%), and requirement-problem questions (1%). Irrespective of this classification, purely process related queries are 43% (e.g. how is the analysis carried out?).
- Structure-related questions (51%) are more compared to behaviour-related questions (3%) and function-related questions (3%). Other 43% questions are purely process related queries.
- Method-related questions (49%) are more compared to properties (32%), component (23%), value (18%), feature (10%), material (10%), environment (3%), manufacturing (2%), assembly (0.3%), and physical phenomena-related questions (0.2%). Only in this classification, the summation of the percentage will exceed 100% because multiple factors are possible to be present in a single question. Purely product related queries are 6% (e.g. how filters are classified?).
- Location-related questions are 6%.
- The questions related to reference to other documents by the analyzed documents are 3%.

In activities,

- Problem solving related questions (91%) are more compared to problem understanding related questions (9%).
- Generate-related questions (82%) are substantially more compared to evaluate-related questions (18%). No select-related query was found.

In types of questions,

- Point questions (56%) are higher compared to descriptive questions (44%).

The conclusions derived from the above results about knowledge captured by the designers were the following.

- Only those answers are captured that are validated.
- Designers captured mainly for generating awareness of proposals rather than interpreting them.
- Designers captured mostly what they designed rather than how they designed (the artefact).
- Designers did not capture many problems in the solutions.
- Mostly the structure of the designed artefact and not its behaviour and function was captured.
- Mainly coarse details of the design (component & properties) rather than its finer details (features and values) were captured.
- Only few requirements and that too in a dispersed manner in the documents were captured. In other words, comprehensive and cohesive lists of requirements are missing from documents.
- Mainly the knowledge created related to problem solving rather than problem understanding was captured.
- Largely, knowledge created related to generation rather than evaluation and selection stages are captured.
- Primarily knowledge was documented in point based answers rather than in illustrative answers.

These independent, single factor-subcategory-based analyses provide a limited view of the structure of the knowledge captured by the designers. It is also necessary to study the relationships between these factors and categories. In the next section we propose and discuss an approach to convert the questions asked into a generic form of questions, and study the dependencies between the categories.

6 GENERIC QUESTIONS

To identify the dependencies between these categories, we convert each question generated from the documents into a generic form. For example,

> *Why is modification at the sharp corners not preferred?*

The question asked was categorized by the knowledge elements mentioned below. The reasoning behind the selection of the particular factor from the taxonomy is explained within the braces.

> *Issue* (concern without solution) → *Knowledge* (intended to interpret the proposals) → *Old* (issue considered before for the artefact being designed) → *Product* (concern about objects being designed) → Solution-problem (concern about problem in the solution) → *Structure* (Concern about a part in the artefact) → *Feature* (Concern about a particular element) → *Problem solving* (try to find a solution to satisfy requirements) → *Evaluate* (intended to assess or criticize) → *Description* (required a detailed answer)

Since including all the categorized elements in a single question will lead to considerable complexity, we have included only those elements that are essential for interpretation of the question in the generic form and kept all other elements separately for understanding the context of the question. The above question, for instance was transformed into the following generic question form:

> *Why was modification to this feature not preferred?* [Issue, Knowledge, Old, Solution-problem, Problem Solving, Evaluate, Description]

The above question links the dependencies between the categories in the proposed taxonomy. The other benefits of creating such generic questions are that it aided us to consolidate the questions, and reduce the apparent variety across the questions generated. These generic questions will facilitate to find the answers from the various sources available in the organization.

7 CONCLUSIONS & FUTURE STUDY

In this paper we explained the knowledge processing activity taken place in an industrial case study using a set of research questions that must be answered in order to provide the understanding needed for enhancing knowledge reuse during product development processes. We proposed a new taxonomy of knowledge, which was developed by analyzing the questions generated from formal documents in industry. Analysis of the questions using the taxonomy helped highlight the major areas of knowledge currently captured by the designers. In order to make explicit the dependencies between the categories in the taxonomy, we transformed each question asked into a generic form. With the help of these generic questions it was possible to explain the aspects in which knowledge captured by the designers were higher. While the sub-groups within each category of the taxonomy are mutually exclusive, the exhaustiveness of the category-set is yet to be confirmed. By analyzing more documents generated for different tasks involved in the design stages we can add further comprehensiveness to the taxonomy. Further work involves doing the above and use that as a basis for supporting capture and structure of knowledge generated during design in order to increase the efficacy of knowledge reuse.

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APPENDIX 1

Topics

Issues: Any problem, concern, or question without an answer is an issue. Some examples for an issue are *"what is wrong in this?", "which line?" and "this you are cutting up to which surface?"*

Proposals: An uncertain statement or assertion which is intended to resolve the issue. Some of the proposals are *"It is the fillet right?" and "That means you taken up to here?"*

Knowledge: If the question is intended to interpret the issues or proposals, it is termed as a knowledge-related query. For example: *What happens if you can't delete this feature?*

Information: If the question is intended to help become aware of the issues or proposals, it is termed as an information-related query. For Example: *Where is the parting surface?*

New: Any utterance related to issue or proposal which was not considered before for the artefact being designed. For example: *This you are cutting up to which surface? ; Which is better?*

Old: Any utterance related to issue or proposal which has been considered before for the artefact being designed. For example: *I see the wall thickness here. Why it is?*

Classes

Product-based: Knowledge or information concerned about objects being designed. The statement such as *"That draft?" and "Which line?"* are classified into product-based knowledge.

Process-based: Knowledge or information concerned about how to design. For example: *This you already did know?"*

Requirements: Technical and non-technical issues about the intended product considered by the designers during the design process. For example: *what is the working hours mentioned for filter head?*

Requirements-problem: The issues or proposals which assess or criticize requirements considered or to be considered. For example: *Why is weight reduction not favourable?*

Solution: The issues or proposals concerned only about the artefact being designed. For example: *What is the merit of this component?*
Solution-problem: The issues or proposals which assess or criticize the artefact being designed. For example: *Why is main filter being improved?*
Requirements-Solution: The issues or proposals that link the artefact being designed with requirements considered, with the intention to assess or critique. For example: *Is metallic filter cleanable?*
Function: The issues and proposals related to what the artefact being designed is intended to do. For example: *what is the function of this filter?*
Structure: The issues and proposals related to the parts and interfaces of the artefact being designed. For examples: *Which line? ; It is fillet know?*
Behaviour: The issues and proposals related to how the artefact being designed will achieve its intended function. For example: *How do you push that?*
Location: The issues and proposals concerns about the position of the artefact being designed. For example: *Where is this feature located?*
Assembly: The subject of the issues and proposals is related to an assembly or a sub assembly of an artefact being designed. For example: *This insert is inserted from top or bottom?*
Component: The subject of the issues and proposals is related to a component of an artefact being designed. For example: *What guides? ; But there is a panel. Why?*
Interface: The subject of the issues and proposals is related to an interface between the components of the artefact being designed. For example: *why are you changing this joint?*
Feature: The subject of the issues and proposals is related to a particular feature of assembly, component, or interface of an artefact being designed. For example: *There are two circles right?*
Manufacturing: The issues and proposals are related to the manufacturing of the artefact being designed. For example: *Can* you heat seal this one?
Properties: A variable representing any quantitative or qualitative property of the designed artefact or its interface to the operating environment. For example: *Tested against ultimate stress?*
Value: A numerical or qualitative quantity, measured, assigned or computed. For example: *What 20-30 mm max?* ; *Should I give more angle here?*
Material: A variable representing any types of material to be used or suggested for the artefact being designed. For example: *There should be steel right?*

Activities

Problem Understanding (PU): PU is interpreted when the broad goal for designers is to try and comprehend the design problem or requirements. For example: *That draft?*
Problem Solving (PS): PS is interpreted when the broad goal of designers is try and find a solution to satisfy requirements. For example: *You cut here only?*
Generate: An activity intended to produce new or elaborate issues or proposals for the artefact being designed. For example: *What colour do you want?*
Evaluate: An activity intended to assess or criticize issues or proposals for the artefact being designed. For example: *What wrong in this concept? ; It is the fillet right?*
Select: An activity intended to take decisive actions on issues or proposals for the artefact being designed. For example: *Keep this fixture constant, Ok?*

Types of questions

Descriptive: The questions which expect elaborative answers were termed as descriptive questions. For example: *What wrong in this concept? ; There is a panel. Why?*
Point: The questions which expect a single word answer were termed as point questions. For examples: *Which line? ; This you already did know?*

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