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Understanding the knowledge needs of the designer during design process in industry

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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. In this paper we propose a preliminary taxonomy of knowledge on the basis of analyzing the questions asked by the designers during interactions. Since the list of taxonomy will only lead to a partial understanding of the needs we converted the questions asked into a generic form with the help of the taxonomy. These generic questions are aimed to provide an understanding about the following: (i) what knowledge must be captured during the design process? (ii) What should be the structure of this knowledge? We believe that this preliminary taxonomy and generic questions should aid in a better understanding of the knowledge needs of the designers.

Keywords: Knowledge reuse, Knowledge representation

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 present 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 exiting 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 design, recovery of design failures, explanation of design process, training to novice, and repeatability avoidance.

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 and a set of research questions framed from that model. Section 4 discusses the various data collection methods employed to collect the required data from the industry, and their limitations. Section 5 proposes the preliminary taxonomy of knowledge observed from the question analysis. Section 6 elaborates the generic questions framed using the taxonomy. Section 7 discusses overall conclusions from these preliminary observations and future works to be carried out are discussed.

2 Literature Survey

In this section we detail the needs to understand the knowledge processing activities, and the challenges and kinds of knowledge representations.

2.1 Need to understand knowledge processing activities

Frankenberger & Badke-Schaub [2] argue that the 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 the 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 fail 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 the 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 the development of standards for knowledge representation will be one of the mechanisms by which knowledge sharing and re-use might be achieved.

2.3 Kinds of knowledge representation

The differences between knowledge management generations are in part illuminated by (Stenmark [13], Hansen et al. [14] and Regli [15]). The distinction between a commodity view or codification strategy or feature-oriented approach (standardized products), and a community view of knowledge 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 [16].

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 [17]. Combinations of both of these approaches have been proposed to help overcome their individual limitations. Systems with such a hybrid approach not only provide logical structure for design rationale, but also record the history of the design process. KBDS-IBIS is such an example [18].

Desouza et al. [19] 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. [20] propose a design reuse model which consists of process 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 [21] discussed 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 the 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.

Alexander and Niels [22] examine how to extract technical engineering knowledge from the experts and creatively represent such knowledge in rich media representations using 3D technologies. They argue that virtual reality and 3D imagery, which are visual information/media generated by 3D technologies, are new forms of knowledge representation that enable the explication of complex product concepts.

Smith and Duffy [23] argue that knowledge from the earlier stages of design (function, behaviour, solution concepts) and the 'how' and 'why' (rationale) of a designed artifact are key elements to the re-use approach.

Yen et al. [24] extract noun phrases from the design knowledge captured and categorized them as product-related and process-related. The categorized broad themes from the study of information requests about designs were requirements, structure/form, behaviour/operation, functions, hypothetical, dependencies, constraints, decisions, justification of alternatives, justification of actions, validation explanations, computations, and definitions.

Malmqvist [25] describes an approach based on an extended version of the function-means tree model of the design process and on 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 [26] describe a technical system and the transformation process that affects 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 [27]). These relations constitute the genetic information of the system and can, hence, be used to describe its design history.

Malmqvist [25] 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 [28]) and overall design process model (Andreasen [27]) 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 includes Functional requirement, Means, Objective and Constraint objects, and Solved by, Altemative solutions and Requirements on and Has influence on relations. He argues that given these specifications, the function-means tree model becomes a simple, yet quite powerful tool for design history representation, capable of representing the basic types design history information listed by Ullman [29].

Szykman et al. [30] represent product knowledge as Requirements, Specifications, Artifact (Sub-artifacts, Functions [Sub function, Input & Output flows], Form [Geometry {Sub geometries, Features}, Materials], Behaviors), Design Rationale, Constraints, Relationships.

Toshiharu and Atsushi [31] build a database, called an ‘engineering history base’, from which engineers can retrieve explanations to enable the reuse of product information. In this paper explanation from the ‘process’ viewpoint is thought to be important in promoting the reuse of product information. Process information is modeled using a Process Unit. A Process Unit is comprised of five elements: *action*, *object*, *alternative*, *constraint* and *reason*. Product information is modeled using three classes: Product class, Data File class and Attribute class. The integration of product information and process information was achieved by product information plays the role of vocabulary for describing process information.

Brissaud et al. [32] propose a descriptive model based on features capitalising on the rationale of 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 [33] 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 [34] defined design history as a representation of the evolution of a product from its initial specifications. He argued 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. A taxonomy of the questions asked by the designers includes category (simple conjectures, conjecture with verification, verification question, open question), topic (assembly, component, interface, feature), age of topic (old, new, specification), nature (construction, location, operation, purpose), confirmation (unconfirmed, confirmed by {examiner, drawings, specifications}), and validity (true, false, unconfirmed, no conjecture). Some of the results were 51% of the questions and conjectures had to do with old topics and high percentage of questions and conjectures were formed concerning the construction of both features and components.

Khadilkar and Stauffer [35] have shown that, for generating new product concepts using information from the previous design effort the designers used both conceptual and detail level information almost in equal proportions, number of queries in construction and the description accounted for almost half of the total queries and the subject-class component level received 43% of the queries.

Eris [36] argues that designing is question intensive. However, our knowledge of the role of asking questions in design is limited. He defines a question as: *"A verbal utterance related to the design tasks at hand that demands* an *explicit verbal and/or nonverbal response.“* He illustrates a strong relationship, a duality, between questions and decisions. He reviewed, compared and extended the taxonomies of questions from four fields: philosophy (Aristotle [37]), education (Dillon [38]), artificial intelligence (Lehnert [39]), and cognitive psychology (Graesser [40]). The table 1 lists the classifications of questions. These classifications could give greater insights to the design rationale even though that is not intended in the original pieces of work quoted.

Table 1 Review of taxonomy from Eris [36]

Philosophy	**Education**	**Artificial Intelligence**	**Cognitive Psychology**	**Design**
Aristotle	**Dillon**	**Lehnert**	**Graesser**	**Eris**
Existence	Existence	Verification	Verification	Verification
(Affirmation)	Instance			
Nature	Definition		Definition	Definition
(Essence)			Example	Example
Fact	Description	Feature Spec.	Feature Spec.	Feature Spec.
(Attribute/ Description)		Concept Complete	Concept Complete	Concept Complete
		Quantification	Quantification	Quantification
	Function	Goal Orientation	Goal Orientation	Rationale / Function
	Rationale			
	Concomitance	Disjunctive	Disjunctive	Disjunctive
	Equivalence		Comparison	Comparison
	Difference			
Reason	Relation		Interpretation	Interpretation
(Cause/ Explanation)	Correlation			
	Conditionality	Causal Antecedent	Causal Antecedent	Causal Antecedent
	& Causality	Causal Consequent	Causal Consequent	Causal Consequent
		Expectational	Expectational	Expectational
		Procedural	Procedural	Procedural
		Enablement	Enablement	Enablement
				Proposal/Negotiation
				Enablement
				Method generation
				Scenario creation
				Ideation
		Judgmental	Judgmental	Judgmental
	Rhetorical			
		Request	Request/Directive	Request/Directive
	Deliberation			

Steiner [41] proceeds to use the 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 [42] 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. Gruber and Russell [43] transformed extracted segments of protocols into a generic question using a limited vocabulary of abstract terminology. The vocabulary used were behavior, 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. They are requirements, structure/form, behavior/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.

For each generic question, there are one or more generic answers. They summarized the range of generic answers, grouping them by the *format* of the answer. The simplest answers to generate are yes or no confirmations and fill-in-the-blank answers. More sophisticated procedures would be needed to generate explanations and other richly structured answers. The classifications of answer are confirmations, atomic answer, list answer, retrieval of historical record, structured descriptions, explanations of how it works, justifications, response to imperatives, response to hypothetical, and evaluations.

Table 2 illustrates the other knowledge representation schemes with merits and demerits found from the literature.

2.4 Challenges in knowledge representation

Barriers impeding the realization of the overall concept of knowledge re-use and sharing are [Neches, 1991]:

- 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 might be implemented.
- The lack of shared sets of explicitly defined terminology, as to how knowledge is described and structured.

Duffy and Legler [44] 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 all lead to the need for supporting methodologies, techniques and tools. Ullman [29] 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 [45] 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 level.

2.5 Summary of literature survey

On average, designers spend 30% of their working time in knowledge acquisition and dissipation during the design process. The efficacy of the designers will be improved significantly only if the 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 the designers. Other schemes attempt only to map the design space. An important

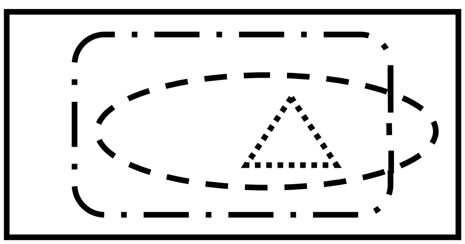
Table 2 Kinds of knowledge representation

Author(s)	Knowledge Representation	Categories	Merits/Demerits
Yakemovic and Concklin, 1990	Issue Based Information System (IBIS)	Issue, Proposal and Argument; and 8 types of relationships among them	Aimed at improving and capturing deliberations during a process. Not sufficient to represent the engineering design rationale.
Potts and Burns, 1988	Potts and Burns Method	Issue, Alternative, Justification and design Artifact; and user derives the relationship between categories	
McCall, R. J. 1991	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.	PHI provides dependency relationships between issue resolutions and considers the pros and cons of alternative answers
McLean, 1991	Question, Option and Criteria (QOC)	Question, Option and Criteria; and several predefined relationships between the categories	QOC's graphical argumentation notation lets team users actively manage QOC recording during work, and supports the transition from expression to documentation, from informal, incomplete, private rationale to more formal, complete, and publicly intelligible rationale.
de la Garza, J. M., and Ramakrishnan, S., 1995	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, 1992	Decision Rationale Language (DRL)	Issue, Alternative, Claim, Goal, Question, Procedure and Artifact; and several predefined relationships between the categories	Detailed set of relationships to capture the rationale is provided.
Chandrasekaran et al. 1993	Functional Representation (FR)	A representational scheme, describes how the device works (or is intended to work).	FR provides a partial rationale for choices made about components and their configuration; FR only captures the causal knowledge about device operation.
Goel A., 1991	Structure, Behavior and Function (SBF)	Explicitly represents the functions of the device (the problem), the structure of the device (the solution) and the internal causal behaviors of the device.	Provide a powerful solution for adaptation problems and for performing case-based and variational design
Rosenman and Gero, 1994	Purpose, function, behavior and structure	Structure exhibits behavior effects function enables purpose: or, purpose enabled-by function achieved-by behavior exhibited-by structure.	Purpose, function, behavior and structure are generally decomposed down to sub-functions, sub-behaviors and sub-structures, so the problem is formulated by the relationship among groups of related functions, groups of related behaviors and groups of related structure.
Blessing, 1994	PROSUS	Predefined categories in the form of matrices to capture the generation, evaluation and selection processes in design	It could be utilized to provide context sensitive support.
Nagy and Ullman, 1991	Object-Relation-Object) OREO	Issue, Proposal, Argument, Constraint, Decision and Design Object; and several types of predefined relationships between the categories.	Information captured is structured based on a hierarchy of issues and decisions chains arranged chronologically.
Ramesh and Dhar, 1992	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.	Expressiveness of the method and power to extract information are good. Large predefined set might find difficult to use.
Nidamarthi, 1999	Designers' activities: Phase, Primary level and Secondary level	Problem understanding (Identify{Perceive, Infer, Modify}, Analyze{Question, Relate, Weigh, Verify, Visualize}, Choose{Decide}) and Problem solving (Generate{Create, Modify, Detail}, Evaluate{Identify characteristic, Question, Relate, Verify}, Select{Identify things to do, Compare, Decide})	Activities of designers are explained. But the product related knowledge is not considered.
Chakrabarti et al. 2005	SAPPhIRE model	State, Action, Part, Phenomenon, Input, Organ, Effect and Relationships	Product related knowledge is explained. But the process related knowledge is not considered.

point to note is that all the descriptive schemes were proposed from the data collected under laboratory settings. The actual knowledge needs of the designers in industry are yet to be observed and answered. Also the knowledge needs of the designers in the different stages of the design process are yet to be studied. The exhaustive representation of product and process knowledge is still a missing entity in the present literature. Also, the dependencies between the product and process knowledge are not adequately addressed. The subsequent sections will address some of the gaps found in the literature survey.

3 Knowledge processing model & Research Questions

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



Knowledge developed
Knowledge worth capturing
Knowledge captured
Knowledge reused

Fig. 1 Knowledge processing model

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

- What knowledge is produced during product development processes?
- What portion of it is currently captured?
- What portion of this knowledge is currently reused?
- What knowledge is developed but not captured that should be otherwise?

In this paper we address the last question. i.e., what knowledge is developed but not captured that should be otherwise. To answer this question we need to understand the knowledge needs of the designers. Therefore we analyzed the questions asked by the designers in various interactions during the design process in an industry. The methods used to collect data are discussed in the next section.

4 Data capture methods & Limitations

To answer the research question a series of case studies was undertaken in a product development organization. Designers involved in different projects were observed for a month each. The data capture methods employed to collect the required data were questionnaires, unstructured interviews, voice recordings and data sheets. Questionnaires were used to collect information about organization, projects and subjects involved in the observations. Unstructured interviews were conducted with the observed subjects whenever it was necessary to understand the subjects' activities or problems that occurred during observation. Voice recordings were employed whenever there was an interaction between the observed subject and other people. Data sheets gave details about the purpose of the tasks, interactions, place of interactions and duration of interactions. The limitations and hindrances that occurred during the observations were:

- The data not produced but eventually understandable in the interactions are context and incomplete sentences, which are later fulfilled by unstructured interviews with the subject.
- The subjects have interacted in languages which the observer was not able to understand.
- The digital voice recorder does not record the voice clearly when the subjects are in motion.

5 Preliminary taxonomy of Knowledge

With the help of data capture methods mentioned in the previous section we captured 70 questions in the various interactions while observing a designer involved in an FEM analysis of a redesign task. The questions were either asked by the observed designer or asked to the observed designer. Initially we classified half of the questions asked by the designers by Aristotle (Table 1) and Dillon (Table 1) to find the relevance of those categories in product development. The classification by Aristotle led to 89% of the questions coming under the 'description-type' and the rest under the 'cause-type' of questions. The classification by Dillon led to 63% of the questions coming under the 'description-type', 11% of questions coming under the 'rationale-type' and the rest subdivided to 'uses', 'conjunction', 'disproportion or equivalence', 'relation', 'existence' and 'disjunction-types'. Neither of these classifications provides a greater insight into the knowledge needs of the designers.

In order to do so, we propose a new, preliminary taxonomy of knowledge needs of the designers. This is based on literature and other observations at study. The taxonomy has four broad categories of knowledge. These are: topics, subjects, activities and how questions were asked. The groups in each category are:

Topics: Issues and Proposals; Information and Knowledge; New and Old.

Subjects: Product-based and Process-based; Function, Structure and Behavior; Properties, Assembly, Component, Interface, Features, Method and Manufacturing; Construction and Location; Requirements and Constraints.

Activities: Problem understanding, Problem solving and Solution understanding; Generate, Evaluate and Select.

How questions were asked: Descriptive and Point.

The groups under each category are mutually exclusive. Chakrabarti et al. [46] 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.

The preliminary results of the knowledge needs of the designers by analyzing the 70 questions asked by the designers using the groups in the category of the taxonomy are:

In topics,

- Issue-related questions (91%) are much higher compared to proposal based questions.
- Information related queries (62%) are higher compared to knowledge related queries.
- Need of old issues or proposals (60%) are more compared to new issues or proposals.

In subjects,

- Product-related artifact queries (58%) are more compared to product-related software queries (22%). But, process-related software queries (18%) are more compared to process-related artifact queries.
- Structure-related queries (71%) are more compared to behavior (25%) and function-related queries.
- Properties-based queries (32%) are more compared to feature (26%), method (11%), component (11%), environment (11%), Assembly (4%), interface (4%) and manufacturing-based queries.
- Construction-related queries (46%) are more compared to location-related queries (14%).
- Requirements-related queries (8%) are more compared to constraints-related queries (1%).

In activities,

- Problem solving queries (58%) are more compared to solution understanding (25%) and problem understanding queries.
- Generate-related queries (66%) are more compared to evaluate-related queries.

These independent analyses only provide a limited view about the structure of the knowledge needs of the designer. It is necessary to study the dependencies between the categories. The next section will discuss an approach to convert the questions asked with a generic form of questions.

6 Generic Questions

To identify the dependencies between the categories in the taxonomy we converted the questions asked by the designers into a generic form. For example,

Why you kept 2D elements?

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

*Issue (*concern without solution) → *Old* (issue considered before for the artifact being designed) → *Process (Software)* (concern about how to design using the software) → *Structure* (Concern about a part in the software) → *Feature* (Concern about a particular element) → *Solution Understanding* (trying to comprehend the solution) → *Construction* (concern about why this feature was used in the construction of the solution) → *Evaluate* (intended to assess or criticize) → *Description* (required a detail answer)

This representation was transformed into the generic question form as,

How do you Describe Issue of Old Solution related to Structure of Process (Software) Feature Construction for Evaluation?

The above question links the dependencies between the categories in the proposed taxonomy. This transformation needs to be further refined to give appropriate structure so as to capture the necessary knowledge produced during the design process. The answer to this transformed question should lead to an answer for the research question-what knowledge is developed but not captured that should be otherwise.

7 Conclusions & Future study

In this paper we explained a knowledge processing activity with the help of a set of research questions that needs to be answered in order to enhance knowledge reuse. We proposed a taxonomy of knowledge needs of the designers by analyzing a set of questions asked during various interactions that occurred in the design process. From the analysis of these questions with the help of the taxonomy, we explained the knowledge needs of the designers involved in an FEM analysis of a redesign task. In order to explicate the dependencies between the categories in the taxonomy we transformed the questions asked into a generic form. This generic form needs to be further refined in order to give a clearer and simpler version of the knowledge needs of the designers. This taxonomy should be validated across the product development stages and designers. The groups under each category of the taxonomy are mutually exclusive, but its exhaustiveness is yet to be guaranteed. More observation of different tasks involved in the design stages lead to an exhaustive list for the taxonomy.

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Appendix

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 helps to resolve the issue. Some of the proposals are *"It is the fillet know?" and "That means you taken up to here?".*

Information/Knowledge: Information and knowledge are relative concepts that cannot be defined in absolute terms. An awareness stage and an interpretation stage differentiate between information and knowledge.

If the question is intended to interpret the issues or proposals then it is termed as knowledge-related query. If the question is intended to become aware of the issues or proposals then it is termed as information-related query. For Example: *Information: This you already did know? Knowledge: You cut here only?*

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

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

Subjects

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

Process-based knowledge: Design knowledge concerned about how to design. The statement such as *"This you already did know?", "You cut here only?" and "Till how long you will be here?"* are classified into process-based knowledge.

Function: The questions related to what the artifact being designed is intended to do. For example: *It will be a part and locked? ;*

Structure: The questions related to the parts and interfaces of the artifact being designed. For examples: *Which line? ; It is fillet know?*

Behavior: The questions related to how the artifact being designed will achieve its intended function. For example: *How do you push that?*

Construction: The question concerns about the manner in which the artifact being designed is made. For example: *That means you taken up to here? Where this radius has gone?*

Location: The question concerns about the position of the artifact being designed. For example: *Which line? Which circle is matching?*

Assembly: The subject of the question is related to an assembly, either the complete assembly or a sub assembly of an artifact being designed. For example: *This insert is inserted from top or bottom? ; This should be assembled outside. Not difficult know. Why?*

Component: The subject of the question is related to a component of an artifact being designed. For example: *What guides? ; But there is a panel. Why?*

Interface: The subject of the question is related to an interface between the components of the artifact being designed. For example: *So in this insert this will come in cavity insert? ; You need to press this one. That is the problem?*

Feature: The subject of the question is related to a particular feature of assembly, component, or interface of an artifact being designed. For example: *There are two circles know? ; Where this radius has gone?*

Manufacturing: The questions related to the manufacturing of the product being designed. For example: *I am having doubt in this process?*

Environment: A specification of the intended environment in which the artifact operates and a characterization of how it interacts with the environment. For example: *how the loading is done?*

Properties: A variable representing any quantitative or qualitative property of the designed artifact or its interface to the operating environment. For example: *Tested against ultimate stress?*

*Method: Any q*uestion related to the design methods. For example: *How do you do shape optimization?*

Requirements: The technical and non-technical issues of the intended product considered by the designers during the engineering design process. For example: *what is the working hours mentioned for filter head?*
Constraints: A constraint that specifies required limits or values to achieve/prevent. For example: *What is the maximum stress for static loading of this material?*

Activities

Problem Understanding (PU): PU is interpreted when designers try to comprehend the design problem. For example: *That draft?*
Problem Solving (PS): PS is interpreted when designers try to find a solution towards satisfy requirements. For examples: *You cut here only? ; If you taken here, then everywhere you will get the tip know?*
Solution Understanding (SU): SU is interpreted when designers try to comprehend the design solution. For example: *This you already did know?*
Generate: The questions intended to produce new or elaborate issues or proposals for the artifact being designed. For example: *So in this insert this will come in cavity insert?*
Evaluate: The questions intended to assess or criticize issues or proposals for the artifact being designed. For example: *What wrong in this concept? ; It is the fillet know?*.
Select: The questions intended to take decisive actions on issues or proposals for the artifact being designed. For example: *Keep this fixture constant, Ok?*

How Questions were asked

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?*