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INDEXING DESIGN KNOWLEDGE BASED UPON DESCRIPTIONS OF DESIGN PROCESSES

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Abstract

The long-term aim of this research is to develop a method of indexing design knowledge that is intuitive to an engineering designer. This research aims to develop a method of indexing design knowledge that is based upon empirical research. Eighteen interviews were carried out with engineering designers from two aerospace companies. The interviews were carried out to understand how designers described the process of designing a particular component or assembly. The analysis of these interviews led to the development of a method of indexing design knowledge.

Keywords: Taxonomies, knowledge management, design understanding, empirical study, indexing

1 Introduction

In engineering design, a large amount of knowledge is generated when designing a product. People other than the original generator of this knowledge can reuse this design knowledge. There are many reasons why knowledge is reused including enabling others to understand the original design process and the rationale behind the decisions made or they maybe working on a similar product. Many systems propose methods of capturing and storing knowledge. Examples of such systems include DEKLARE, a methodology that supports engineering redesign or PROSus which captures the rationale behind designs [1,2]. In order, for knowledge to be reused it must be retrievable from any such system. Indexing design knowledge is one method to support the retrieval of knowledge from a system. The design knowledge, which may be in many formats including memos, emails, sketches, reports, etc., is indexed when it is captured into a system. Current approaches to indexing design knowledge include automated indexing such as Dedal AI, which can improve the precision and recall of boolean searches [3]. Dedal AI automatically indexes parts of a query by identifying generic design concepts. Evbuomwan describes the need for retrieval methods to address: 1) indexing mechanisms for handling, specifications and constraints; 2) indexing mechanisms for handling and maintaining the decompositional links between design solutions and sub-solutions; 3) indexing mechanisms for accessing materials, manufacturing process, parts, subsystems, layouts or architectures, etc; and 4) indexing mechanisms based on functionality and uses [4].

2 Research approach

The long-term aim of this research is develop a method of indexing design knowledge that is intuitive for the engineering designer. Therefore, empirical research was carried out to understand how designers describe their processes of designing a component or assembly that they were familiar with. If these descriptions could be broken down to identify a common classification, this classification could form the basis for a structure for indexing design knowledge. Prior to the empirical research study, it was hypothesised that the descriptions of the design process could be classified in four ways:

- the process itself, i.e. a description of the different tasks undertaken at each stage of the *design process*. For example, past design search or brainstorming.
- the physical product to be produced, i.e. the *product (component, sub-assemblies and assemblies).* For example a turbine blade or the root of a turbine blade.
- the *functions* that must be fulfilled by the particular component or assembly. For example one of the functions of a compressor disc is to secure the compressor blade.
- and whilst carrying out the design process there are several considerations the designer must make whilst designing, i.e. *issues*. For example, considering the unit cost or manufacturing considerations.

In addition, to obtaining descriptions of their design processes from the designers, the interviews were also used to evaluate two taxonomies. One of these was a taxonomy of *issues* and the other of *functions.* Taxonomies are described in more detail in the following sections. The taxonomy of issues was generated by one of the collaborating companies. Hence, by conducting interviews in two companies, the issues taxonomy could be evaluated to identify the issues that were company specific and those that were generic. Descriptions of the steps of a design process and taxonomies that describe the breakdown of product were not tested, but generated during the interviews. The reasons for this were:

- these taxonomies are specific to the *particular product* or *design process* being described during the interview
- and generic taxonomies have been described widely in the literature, e.g. [5].

2.1 Issues

There are several considerations a designer must make whilst designing a product. These considerations have been referred to as *issues*. Issue is a very general term, referred to by many researchers particular in relation to Issue-based information system (IBIS) [6]. Therefore, in order to define the issues considered by designers, an attempt to generate a list of issues was made. The following two approaches were undertaken:

1) Transcripts of observations of novice and experienced designers were analysed to identify the issues that the designers considered [7]. Four classes of issues were identified, issues that related to: 1) the lifecycle of the product; 2) the environment of the product and interfaces; 3) the functionality of the product; 4) and the characteristics of the product. The transcripts of the designers represented only 12 different design tasks within the aerospace industry, therefore the analysis of the transcripts was useful to identify these four classes of issues. However, the analysis could not be expected to generate a complete list of issues. Therefore, a second approach (described below) was taken.

2) A list of sixty issues specific to the aero-engine was identified by collecting together checklists of considerations that designers make whilst designing a particular component or assembly. These were developed by designers from company A. The researcher grouped these issues within the four classes described above, it was possible to classify all of these issues. These issues include those related to the product lifecycle, e.g. manufacturing; interface and environment, e.g. the operating temperature; the functionality of the product itself; and the characteristic of the product, e.g. structural properties (refer to Figure 1).

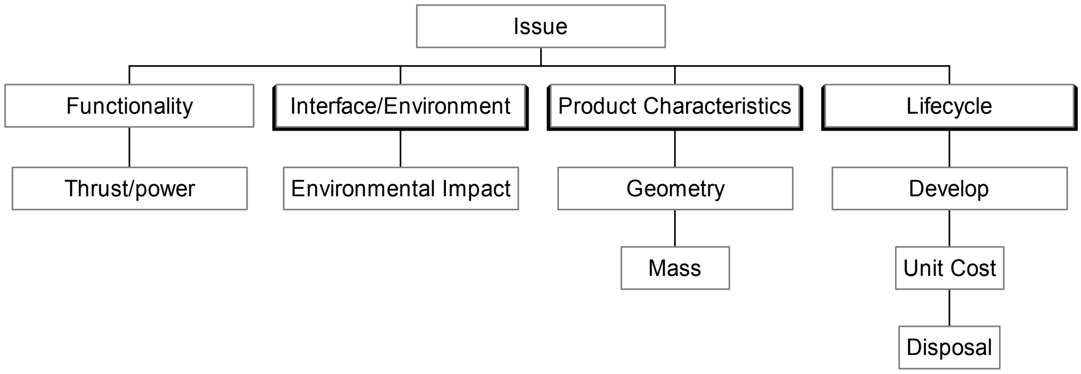

Figure 1. Issue taxonomy: Generic classes with examples of issues

2.2 Functions

The taxonomies of functions evaluated for their suitability of indexing design knowledge were those developed by Szykman *et al* and that of Hirtz *et al* [8,9]. Szykman *et al* describe a taxonomy representing functions and flows that are applicable to a broad variety of engineering artefacts. The taxonomy aims to facilitate the capture and exchange of function information. The taxonomy developed by Hirtz *et al* integrates the efforts of Szykman *et al* with those of Stone and Wood [10]. The resulting taxonomy is referred to as the functional basis with a set of functions (verbs) and flows (nouns). A function of a component or assembly can be described using the list of verbs combined with a list of nouns, for example: fasten material solid object rigid-body. Hirtz *et al* state the facilitation of indexing, search and retrieval of information as one of their motivations for the taxonomy.

3 Research method

Eighteen engineering designers with differing levels of experience and from two different companies were interviewed. Both of these companies are large aerospace companies based in the UK. The engineering designers interviewed were all graduated with degrees in mechanical engineering. Their experience within the aerospace industry ranged from 2 to 42 years. Therefore, the designers were grouped into three different groups:

1) designers with under 5 years of relevant experience
2) experienced designers with between 11 and 23 years of relevant experience
3) designers with between 28 and 42 years experience who had moved on to more managerial roles and were no longer directly designing.

A summary of the participants is presented in Table 1. Each row of the table describes the level of experience; the current team and; the assembly discussed. Designers 1-11 were all from the same company working on various assemblies of the aero-engine and designers 12-18 were from the second aerospace company working on various assemblies of the aircraft.

Table 1. Level of Experience of Interviewees

Designer	Experience (years)	Company	Component or Assembly
1	11	Company A	Turbine Casing
2	18	Company A	Turbine Intermediate Pressure Casing
3	11	Company A	Turbine Internal Casing
4	20	Company A	High Pressure Compressor Casing
5	23	Company A	High Pressure Compressor Drum
6	2	Company A	Compressor Rotor Blade
7	4	Company A	Compressor Intermediate Annulus Line
8	4	Company A	Compressor Disc
9	2.5	Company A	Compressor Intermediate Pressure Rear Cone
10	2	Company A	Fans System Inner Ring
11	5	Company A	Fans System Inner Ring
12	28	Company B	Wing
13	27	Company B	Keel Post
14	39	Company B	Fin
15	30	Company B	Concept Aircraft
16	39	Company B	Refuel Door Panel
17	42	Company B	Aircraft Hydraulics
18	36	Company B	Fore Plane

During the interviews the designers were asked to describe the process of designing a particular component or assembly. The designers were asked to select an assembly that they were currently working on or had recently been working on (refer to Table 1 for a list of assemblies). The designers were allowed to talk freely and were not interrupted or prompted. Care was taken to ensure that none of the expected results were communicated to the designers prior to the interviews to avoid any biasing of the results.

In addition to collecting descriptions of the process of designing a particular component or assembly, the interviews also provided an opportunity to evaluate the suitability of two taxonomies for the purpose of indexing design knowledge. As described earlier, these two taxonomies were; descriptions of functions using verbs and nouns; and a list of issues. The evaluation of these taxonomies was conducted after the designer had described their design process to avoid biasing their descriptions of the design process.

In order to evaluate the function taxonomy, the designers were asked to describe the breakdown of the assembly or sub-assembly that they were familiar with. Each of the assemblies was broken down into components and features. The designers were asked to describe the function of each feature or component. The designers were shown examples of verbs and nouns that could be combined to describe functions. However, they were not asked to use any particular set of verb or nouns and were able to describe the functions of each component or feature using their own words. The designers did not refer to the list of verb and nouns.

The designers were also presented with a list of issues (described in section 2.1). The issue taxonomy was evaluated from three perspectives:

1) Completeness: The designers were asked if they considered any issues whilst designing which were not on the list.

2) Issues specific to particular components or assemblies: For each issue, the designers were asked to state if they considered that particular issue when designing the component or assembly discussed. The designers stated whether the issue was considered directly; indirectly (the issue was a consideration for that component or assembly but was considered by a different designer; or not at all.

3) Issues specific to the particular stage of the design process: For each issue, the designers were asked at what stage or stages of the design process the issue was considered. However, the taxonomy was at a too high granularity for this to be evaluated. For example, the issue *manufacture* may involve selecting manufacturing processes at an early stage of the design process and may involve specifying tolerances at a later stage. Since the issue was termed *manufacture*, it was not possible to capture these differences. Therefore, the second set of interviews at company B did not pursue this aspect of the evaluation.

4 Findings

The following sections present the preliminary findings from the interviews, however further analysis of the interviews is currently underway to gain a deeper insight.

4.1 Design process description

Each description of the design process was transcribed. The transcripts were broken down into small segments. Each segment was analysed to identify any of the following:

- any descriptions of the different tasks at each stage of the *design process*
- references to the *product* including component, sub-assemblies and assemblies
- references to the *function* that must be fulfilled by the particular component or assembly,
- references to *issues* that need to be considered.

An example of an analysed section of transcript is presented in Table 2, the first column is the designer’s own words, each row represents a segment of the description and are consecutive segments.

Table 2. Example of analysed description of design process

Designers description	Design Process	Product	Function	Issue
Define the material in order to assess weight and cost	Material selection, cost assessment, weight assessment			Weight, unit cost
Look at past designs, for new concepts to see how they fit into the space specified	Past design search			
Think of manufacturabilty				Manufacture
Think of assembly at a component and module level		Component/ module		Assemble
Cost/function analysis, overall and individual costs	Cost/function analysis			Unit cost
Logistics, supply change, e.g. if its made abroad				Transport deliver
Contain blade: calculation to check this	Calculations	Blade	Contain blade	
Pressure dilation, calculate if strong enough as a pressure vessel	Calculations		Withstand pressure	

The breakdown of the description of the design processes is shown in Figure 2. Each segment of the description referred to steps of the design process; components or assemblies; the function; or issues; or any combination of these. Therefore, the graph does not add up to hundred percent, but instead represents the percentage of the description that referred to each of these. On average 56% of a designer's description of the design process referred to issues that were considered; 19% referred to steps in the design process; 17% referred to products including the component or assembly being designers and surrounding components and assemblies; and 7% referred to the function of the component or assembly. The preliminary analysis of the interviews found that the descriptions of the design processes could be classified within these four classes and no additional classes were identified. However, *find relevant documentation* was mentioned by two of the designers, this was classified under *design process* and highlights the need to define the process to cover such tasks.

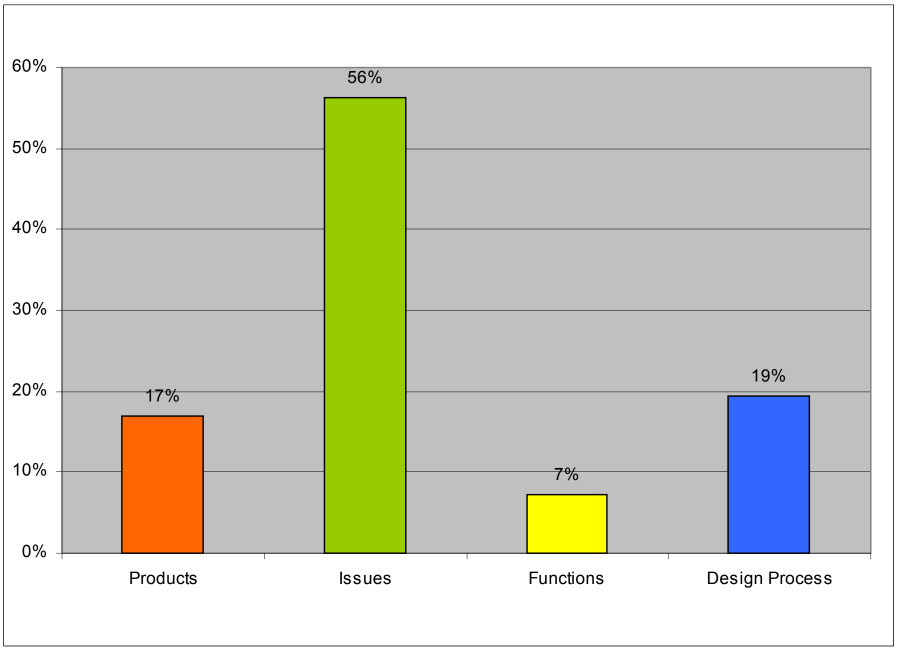

Figure 2. Breakdown of description of design processes

The descriptions of their processes varied with their level of experience. Figure 3 shows a breakdown of the descriptions of the design process against the level of experience of the designers. The designers with between 11 and 23 years of relevant experience referred to functions for 16% of their descriptions this was significantly higher (four times higher) than the designers with under 5 years of experience or the designers with between 28 and 42 years who were no longer designing.

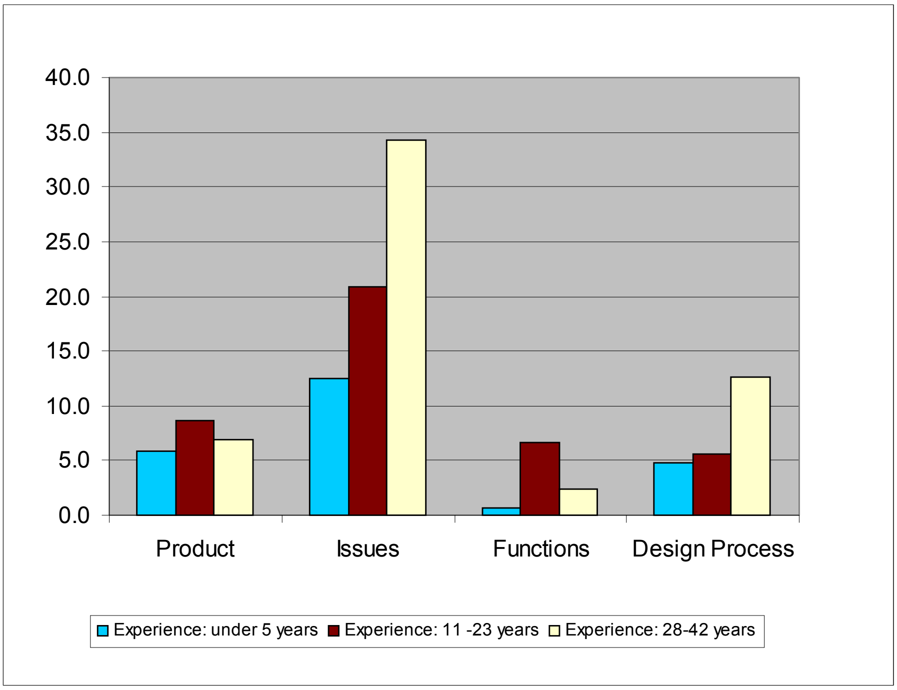

Figure 3. Breakdown of descriptions of design process versus experience

The level of experience also influenced the number of references to steps of the design process; components or assemblies; the function or issues. On average, the more experienced designers mentioned almost twice as many references in their description of the design process than the designers with under 5 years of experience (see Table 3).

Table 3. Number of references to products; issues; functions; and steps in the design process

Level of experience	Product	Issue	Functions	Design Process	Total
Under 5 years	6	13	1	5	25
11-23 years	9	21	7	6	43
28-42 years	7	34	2	13	56

4.2 Evaluation of function taxonomy

In total 86 descriptions of functions were collected from designers 1-11 from company A and have been analysed. A further 121 descriptions of functions were collected from designers 12-18 from company B, however these are not yet analysed. The 86 descriptions of functions were compared to the verbs and nouns of the taxonomy of Szykman *et al* and Hirtz *et al* [8,9]. The preliminary analysis of the description focused upon the verbs used by the designers. These verbs were compared to the two taxonomies; a direct match, indirect match or no match was recorded. A direct match was defined if the verb used by the designer was the same as that from the taxonomy. An indirect match was recorded if a synonym was used or if it was possible to restate the description of a function with a combination of a verb and noun from the taxonomy. If the designers' description of the function could not be restated, no match was recorded. The nouns were also abstracted to be at the same level as the nouns from the taxonomy, for example, *blade* became *material: solid object: rigid-body.* The preliminary analysis of the taxonomies describing the function that a particular component or assembly has to fulfil is summarised in Table 4. The taxonomy of Hirtz was found to directly match 63% of the verbs that the designers used, which was a significant improvement on the earlier taxonomy of Szykman. However, between 31% of this was not matched directly, i.e. a suitable alternative description of the function had to be found from the taxonomy. The reasons for an indirect match of verb extends further than the use of a synonym and will be investigated further.

The analysis has been completed for the interviews that have been carried out at company A but those from company B have not yet been analysed. Once the analysis for both companies has been completed an insight into the influence of the company culture can be obtained.

Table 4. Evaluation of function taxonomy: matching of verbs

Taxonomy	Direct match	Indirect match	Total matched	Not matched
Szykman *et al*	26%	65%	91%	9%
Hirtz *et al*	63%	31%	94%	6%

4.3 Evaluation of issue taxonomy

On average the designers with under 5 years experience considered 30 out of the 60 issues, the designers with between 11- 23 years experience considered 43 of the issues and the designers with between 28-42 years of experience considered 46 of the 60 issues. Therefore, the experience of the designers influenced the number of the issues that the designer considered. All of the sixty issues were stated as relevant by at least one of the designers. One additional issue was identified from the interviews that was not on the list, this was *corrosion.*

Table 5. Number of issues stated as relevant

Level of experience	No of issues (out of 60)		
	Directly relevant	Indirectly	Not relevant
Under 5 years	30	2	28
11-23 years	43	2	16
28-42 years	46	4	10

The set of issues applicable to company A was compared to those applicable to company B to identify the issues that are generic and those that are specific. There was no significant difference between the designers from company A and those from company B in the number of issues considered. It was found that the general classes are applicable to both companies, i.e. issues that are considered by the designers can be grouped as related to the lifecycle of the product; the environment of the product and interfaces; the functionality of the product; the characteristics of the product. The specific issues did differ between these companies. The reasons for these differences are described below:

- The terminology used to describe the issue differed between the companies
- The designers would consider a different aspect of the issue, for example *thrust/power* was thought of as *lift/drag*.
- The issue was specific to that particular product (or component and assembly), f
- or example, as the functionality of the product differed the list of issues related to the functionality also differed.

The stage of the design process may affect the issues to be considered, however, the taxonomy tested may be at a too high granularity for this to be evaluated.

5 Conclusions

Structured interviews with engineering designers from two separate aerospace companies have been carried out to develop a method of indexing design knowledge. Descriptions of the process of designing components or assemblies have been collected. The analysis indicated that these descriptions could be classified into four classes; steps of the design process; components or assemblies; the function; or issues; or any combination of these. The preliminary results from the interviews have supported the direction of the proposed indexing structure. The descriptions of the design process differed with the level of experience of the designer. The interviews were also used to evaluate two taxonomies; one describing a list of issues and the other functions. The initial analysis indicates that issues considered by a designer can be grouped within four classes, those related to the 1) the lifecycle of the product; 2) the environment of the product and interfaces; 3) the functionality of the product; and 4) the characteristics of the product. The taxonomy of functions, found that 94% could be matched, however, a third of these were not matched directly. Therefore, further research is required to understand the reasons for this and also to develop the taxonomy of issues further.

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