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A STRATEGY FOR ARTEFACT-BASED INFORMATION NAVIGATION IN LARGE ENGINEERING ORGANISATIONS

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Abstract

Central to an effective information management or knowledge management strategy - particularly where the KM strategy focuses on the capture and codification of knowledge - is the ability to efficiently and effectively access information. This includes finding and re-finding the right information in the right amount at the right time. For many large organisations, and in particular engineering organisations that design, build and service a wide range of complex long-life products, the volume of information (knowledge) that is captured and stored, and the variety of users and their information needs make the provision of appropriate information access tools a major challenge. By way of an alternate to extant text-based tools, the work reported in this paper explores the concept of artefact-based information search within the context of large engineering organisations.

Keywords: Knowledge management, Information management, Visualisation

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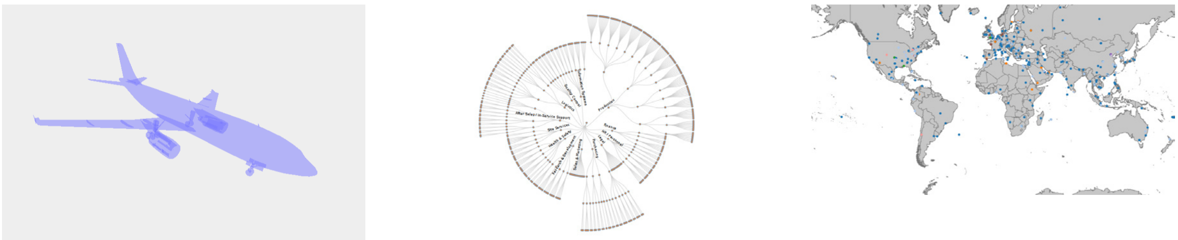
1 INTRODUCTION

Knowledge Management (KM), the capture, storage and dissemination of an organisation's knowledge is seen as a key component to competitiveness. As such, companies like the Airbus Group treat KM as a discipline in its own right and invest in the long-term codification and reuse of knowledge throughout and across product life-cycles such as capturing lessons learned reports, providing business search tools and generating directories of experts. Since the conception of KM, academic literature has discussed widely the importance of knowledge management activities and developed numerous approaches to better capture information within engineering organisations (Dyer and Nobeoka, 2002, Haas et al., 2003, Pardessus, 2004, Alavi and Leidner, 1999). While work exists that examines the different techniques of knowledge dissemination both in general (Alavi and Leidner, 2001) and through systems specific to engineering (Aurisicchio et al., 2006, Li et al., 2008, McMAHON et al., 2002) the arrival of HTML5 and web browser base 3D animation and visualisation (Parisi, 2014) opens up possibilities for advancements in the field with next generation of user interfaces.

The work put forward here forms part of a project examining whether an improvement can be made in how engineers access information (codified or captured knowledge) by the re-representation of engineering information within a visual artefact model. The artefact model being a real world representation of the task in which the engineer is engaged in; be it a 3D Airbus A320, a node-link tree representation of the organisational structure or a world map (c.f. Figure 1). The goal is to construct a system that moves the engineer away from the traditional text based search boxes and lists of results, to an interactive visual representation more akin to the engineering task and form of visualisations e.g. geometric or functional that are familiar to the typical engineer.



(a) *(b)* *(c)*

Figure 1. Example of engineering artefacts (a) an Airbus A320 (b) organisational structure and (c) a world map.

This paper discusses a strategy for creating such a system and highlights some of the techniques and challenges for its realisation. The discussion takes place around a prototype system based on a Formula Student racing car and associated final year student reports. Firstly, a brief background to knowledge management is given before the principles and software implementation of a prototype system are discussed. Finally, we consider some of the challenges envisaged in implementing the system within the context of a large engineering organisation and complex product/lifecycle.

2 BACKGROUND

The benefits of the capture and dissemination of information within design are widely known and the challenges of facilitating these activities are widely discussed in literature (Dyer and Nobeoka, 2002, Haas et al., 2003, Lowe et al., 2003, Pardessus, 2004, Alavi and Leidner, 1999, Alavi and Leidner, 2001, Hicks et al., 2010, Hicks et al., 2002). While there is a consensus that IT systems alone are not enough to solve the wider problem and the engineer must embrace KM and KM practices (Sheriff et al., 2013, McDermott, 2000), there are a number of articles that address the benefits and design requirements of IT systems for knowledge management (Alavi and Leidner, 2001, Bowman, 2002, Szykman et al., 2001). In particular, (Szykman et al., 2001) examine KM in the next generation of Product Development Systems (PDS) and highlight a major challenge for KM systems as the move from exchanging purely geometric data to the sharing of *"...more general knowledge about design and the product development process, including specifications, design rules, constraints and rational."*.

Not only are engineers capturing and disseminating more knowledge but the audience for that knowledge is also growing as companies collaborate across multiple sites often in different countries and outsource work to third parties. (Szykman et al., 2001) continue by calling for the next generation of PDS to allow sharing of knowledge across "*...a set of heterogeneous set of software tools…*" that accommodates the way differing companies will have different software requirements and so use different software systems.

This requirement is true also of a large organisation where the knowledge can be stored in a variety of systems across multiple sites and even sometimes across different organisations in a group. (Szykman et al., 2001) calls for all future systems to be built with knowledge management in mind allowing the transfer of data between systems. If this happens in the future then it may address the KM issue but it does not directly make available historical data that organisations currently have. The question is, are there any current tools or techniques than can be combined to allow for the next generation of KM systems without having to rely on the major software providers agreeing to work together e.g. through standards or standardisation both of which can take decades to achieve.

Currently, organisations rely on web technologies to power their Intranets and this is understandable given they offer an IT infrastructure that is platform independent and designed to provide information on request with search and standardised formats (Hustad and Vikstøl, 2014). Where Internet technologies fail to meet KM demands is in how successful Internet search techniques are for indexing and retrieving file types that are not web standard and where files are not optimised for retrieval. While it is standard practice to implement search engine optimisation techniques to increase web page ranking on the Internet, few similar techniques exist for an organisation's data and yet we all expect an Intranet search to be on par with an Internet search. While a solution to this could be to better enforce practices such as meta tagging, this does rely on employees to understand the context and usefulness of their documents within the wider context of the organisation as well as knowing the acronyms and synonyms used across the different organisational functions.

3 ARTEFACT-BASED INFORMATION NAVIGATION

In contrast to traditional text, artefact-based navigation aims to improve Intranet search and so knowledge discovery/dissemination by taking a slightly different approach to the problem while at the same time relying on and utilising the advantage of web technologies. Artefact-based information search contextualises information with respect to a metaphor or artefact representation which is relevant to the organisation, product and the task, and therefore familiar to the actor (engineer). This re-representation through a visualisation of an artefact has the potential to: (i) provide means to integrate heterogeneous information sets; (ii) better support information navigation; (iii) improve the ability to find and re-find information in terms of time reduction and relevance of information and (iv) provide a means to evaluate (visually) the information/knowledge assets e.g. coverage across a product or supply chain.

The concept of representing information in a visual space is not new but a literature review has not revealed an approach equivalent to the one proposed here, although similar work does exists. Building Information Management (BIM) systems (Eastman et al., 2011) represent buildings in a virtual space where they are constructed from their constituent objects and object attributes (structural material, acoustic data, energy efficiency, etc.). The key difference between BIM and the proposed system is BIM facilitates the discovery of building information through attributes whereas the proposed system facilitates the discovery of enterprise wide information. (Pecchioli et al., 2011) discuss a system for the navigation of Cultural Heritage information in 3D virtual environments (ISEE: Information access through the navigation of a 3D interactive environment). As the user 'looks at' certain buildings and objects, the relevant documents/information are presented. The authors also go beyond the virtual environment and present a case study of an individual moving through the Piazza Napoleone in Italy, the real world GPS positioning is paired with the system to show real time information as the user navigates the real world. This system is closer to the artefact-based system proposed here in that the system navigates a range of information and one could argue the artefact in this case is real world locations and building. The novelty of the proposed artefact-based information navigation is in combining these two approaches within the space of design and manufacturing, generating artefacts that are relevant to the actor, that contain the hierarchical and functional nature of BIM systems and the information discovery aspect of ISEE.

In achieving this, two significant challenges must first be met. These concern: how to utilise traditional search indexes in such a way that they index an organisation's files in a more meaningful and useful context and how to disseminate information in a method that improves knowledge discovery. Each of these challenges is now considered.

3.1 Search Indexing for Organisational Data

In Internet search, web pages are pre-processed to generate a search index and when the user performs a search it is the index that is processed rather than the entire Internet. Pre-processing massively increases the performance of search engines and it is how the large Internet giants can return hundreds of thousands of results in fractions of a second. These same pre-processing techniques are used in Intranet searches and can do the same job of returning numerous results in short periods of time (hardware dependant).

The first step in generating a search index involves Term Extraction (Information Retrieval or Automatic Term Recognition), parsing text and extracting the terms contained. This is the process where 'meaningless' words (stop words) are discarded *(as, able, about, above, according, accordingly, across, actually, after, afterwards, etc.)* and the remaining terms added to the index. An inverted search index can be thought of as two columns: a dictionary column and a posting column. The dictionary is the term itself and the posting is the ID of the document containing that term. Searching the index is a case of working through the dictionary list and returning the ID of any matches. The ID is then used to return the documents or at least a summary of the documents captured. This process is reinforced by adding keywords to the website. Keywords being a list of terms that users are likely to use when searching for a particular type of website. Matching the words on your website to the terms that users search for increases where the website is positioned in the results. Keywords are generated from user search queries and user behaviour and as such are only available as distributed by the search engine, an example being Google's AdWords or Yahoo's Overture.

Generating a keyword suggestion tool could be one way of improving the way organisations can meta tag documents and so improve search results. This does still rely on the user to both participate in the process and understand the context of their document in the wider organisation both in use and in the different synonyms used. (Nakagawa and Mori, 2002) discussed the process of Automatic Term Recognition and states how 85% of domain specific terms are said to be uninterrupted collocated nouns (i.e. aeroplane wing, landing gear) and the remaining 15% are single nouns (i.e. aeroplane, wing, gear). At the very least the term extraction process for Intranet should be limited to domain specific terms to eliminate a large proportion of noise in results. It stands to reason that while searching an organisation's Intranet a user will be looking for domain specific documents and using domain specific term queries, hence the search engine index should mirror this.

3.2 Knowledge Dissemination

The use of domain specific term indexes should improve the precision of search results but there is a further opportunity to provide context and remove any issues with synonyms that is very applicable to the world of engineering. In (Henderson, 1991) the author observed and participated in the daily activities of engineers engaged in the design of a turbine engine. During these activities the author noticed the importance of visualisations (sketches, drawings and CAD) to convey knowledge between the team and concluded that engineers naturally rely on boundary objects when disseminating knowledge. It is this finding that an artefact-based search system aims to take advantage of, i.e. to re-represent search results within a visual model rather than the text query and text based lists of results that most search engines currently use.

So, the first benefit of this approach is as stated: engineers naturally think and work visually or functionally and so presenting information/knowledge in such a visual form rather than textually should improve the dissemination of knowledge within an engineering environment. This approach has additional benefits too. Aerospace and structural engineers might use different terminology to describe the components of a wing, referred to as the synonyms problem. Text based systems rely on synonyms being known by the user (used to either meta tag or as part of the search query) or built into the search engine itself. The visual approach does away with this as both engineers will navigate to the same component on the wing regardless of what each person considers that component to be named. This allows for better cross function knowledge dissemination without the need to share synonyms.

An artefact-based approach may also provide context to the search in the same as Ontologies hold the relationship between terms for search engines (King and Reinold, 2008). For example search ontologies aim to capture that an aileron is part of a wing which is part of an aeroplane. Further, it is contended that a better understanding of the context of a search will improve the accuracy of results. For example, being able to eliminate results for *wing of a building* or *chicken wing* when the user searched for *aeroplane wing*. An artefact representation would provide such ontology without having to rely on any automated algorithmic techniques or manual input.

4 ARTEFACT-BASED INFORMATION SEARCH - A WORKING EXAMPLE

Like the US-based Formula SAE and the Australian Formula SAE Australasia, the Institution of Mechanical Engineers in the UK run the undergraduate motor sport competition Formula Student, where teams of students from across the world compete to design, build, test and race a small single seat racing car. The end of year reports, Bill of Material (BOM) information and a 3D model racing car were obtained from a 2013/14 team. These were combined and used to construct a working prototype of an artefact based search system in an attempt to demonstrate the viability of such a system and scope feedback from users that will guide future iterations of the system. This section examines the data and discusses the construction of the visualisation and prototype.

4.1 The Process

The artefact-based search system is based on a traditional Linux-Apache-MySQL-PHP (LAMP) server architecture, see Figure 2 (a).The MySQL server stores the index and summary of each report. Apache web server serves the web pages and PDF reports on request. The web page itself is based on JavaScript and HTML5 and is designed to run in the web browser on the local machine, this allows the visualisation to maximise the processing potential of local graphics hardware rather than rely on the server itself. Figure 2 (b) shows the process diagram for the construction of the live system. Starting with the pre-processing of the PDF reports and moving into the live system and the user interaction. The remainder of this section describes each of these processes in detail.

(a) (b)

Figure 2. Artefact-based search system (a) LAMP architecture and (b) process diagram.

4.2 Pre-Processing

The dataset consisted of 52 undergraduate final year reports containing an average of 6541 words describing the design and testing of a particular racing car component. This content therefore gave a strong correlation between the structure of the vehicle and the text in the report. The documents were in PDF format which meant they could not be directly parsed easily and indexed. Consequentially, the Xpdf Linux command line tool pdftotext (Labs) was used to first convert the PDF files into plane text files. The text files were then parsed to extract all single nouns and uninterrupted collocated noun chains and these terms were then stored in a MySQL database in an inverted index table using the unique document title as the document ID.

Alongside the final year report, each team was required to submit a Bill of Materials (BOM) for their racing car. These came in the form of Excel spreadsheets and provided a complete list of all components that made up the car. This allowed for the labelling of the major components in the model using a consistent set of domain specific terms that were independent to those derived from the content of the reports. This independent set of terms provided the opportunity to validate the domain specific term extraction process based on the principle that every report should be linked to the model via a shared domain specific term.
The model is half a Formula Student racing car that has been converted into the STereoLithography (STL) format (Jacobs, 1992) to simplify the structure and to limit the load on the computer hardware. The visualisation was constructed in WebGL (Parisi, 2014) using the JavaScript library Three.js (Dirksen, 2013). WebGL is the web based equivalent to OpenGL which allows the web browser direct access to the computer graphics card and allows 3D acceleration and so more powerful 3D visualisation inside the web browser. Three.js is a JavaScript library that simplifies the way WebGL is programmed and contains the API required to directly load STL models in the browser. See Figure 3 for the model viewed in the Firefox web browser on Ubuntu 14.04.

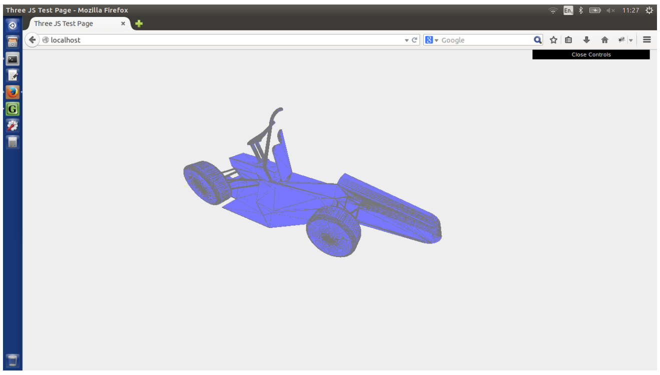
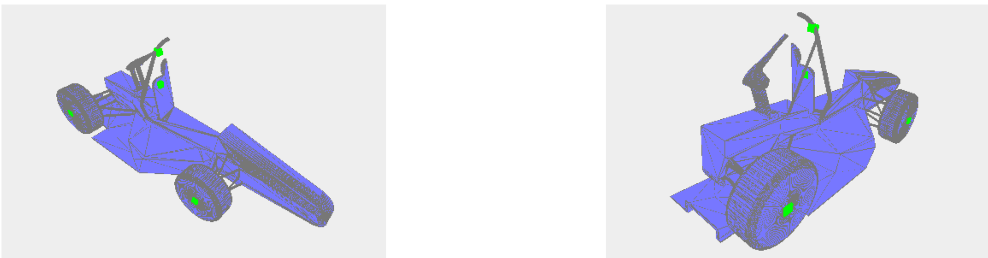


Figure 3. 3D STL model of a half of a Formula Student racing car visualised using Three.js and viewed in a Firefox web browser running in Ubuntu 14.04.

Three.js centres the model around the origin at the very centre of the screen. Spinning the model is achieved by mouse clicking and dragging. Middle click on the mouse and sliding back and forwards handles the zooming. Points of Interest (POI) (Olsen et al., 1993) are added to the model in the form of green cubes, see Figure 4 (a) and Figure 4 (b). POI represent particular components, Figure 4 (a) and Figure 4 (b) show the front and rear wheels, the seat and the main roll hoop. The POI are positions using a global 3 dimensional coordinate system and the points remain fixed in the model space as the model is manipulated. Any points visible on screen are captured for the search query.



(a) *(b)*

Figure 4. The Formula Student racing car from the front (a) and back (b) with added Points of Interest (POI) to represent the front and rear wheels, the seat and the main roll hoop.

5 LIVE SYSTEM AND USER INTERACTION

The basis of the artefact-based information search is that results are filtered according to the manipulation of the model and results view. For example, viewing the whole of the car and so all POI generates a list relative to the coverage to the information in the artefact, in this case all results. As the visualisation is manipulated to show subsystems or particular components, the results are filtered accordingly. Figure 5 (a) to Figure 5 (c) show the user navigating from the initial position showing the entire racing car to focus on the front wheel and suspension system. As each view changes the results window updates in response. Figure 5 (d) shows just the results window, each result consists of a hyper-link to the document and the summary section of the report. On the right hand side of the screen, in the same plane as the hyper-link, the POI label is displayed. Results are ordered by the number of times the POI label appears in the document. Finally, Figure 5 (e) shows and example of a report being opened and viewed in the web browser.

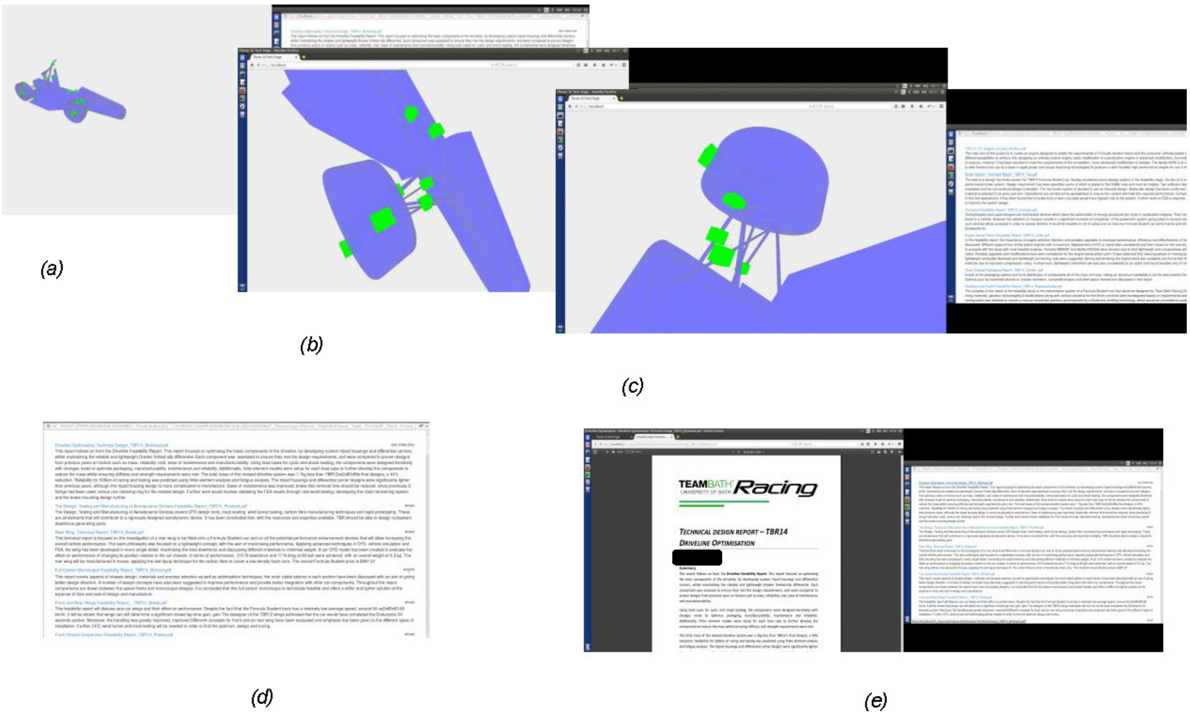


Figure 5. The artefact-based search system showing (a) entire results for all POI (b) the front wheel & suspension system, Monocoque Chassis and Frame Paint POI (c) alternate view of the front wheel (d) a close up of the results page and (e) an opened PDF student report.

6 IMPLEMENTATION CHALLENGES FOR A GLOBAL ORGANISATION

Based on discussions of the demonstrator system with engineers form various departments and a review of literature from other fields e.g. BIM, a number of interrelated challenges have been elicited.

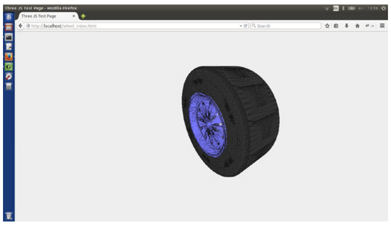
6.1 Dealing with Big Data

The current visualisation visualises 18 POI focusing mainly on the larger racing car components. As the dataset and model complexity increases a strategy will be needed to manage the number of POI on screen at any one time. For example, while viewing the entire car the wheel is visible but should the wheel nuts, brake pads, ball joint, bearings, etc. all be visible at the same time or should they appear as the user zooms into the wheel? There is also an issue of how to differentiate between POI that are close together. Figure 6 (a) and (b) shows an example solution to this. As the user zooms in to the wheel, the rest of the model disappears leaving just the tyre and wheel rim Figure 6 (a). The figure also shows the tire and wheel exploded along one axis Figure 6 (b). To demonstrate this problem, consider the number of components in the Airbus A380 and combine that with the hundreds of thousands of CAD drawings, pictures, photographs, video and text documents that where generated during the A380 life-cycle to date. By way of an example of the volume and diversity of data being considered, the current Airbus Group public lessons learned catalogue consists of 2083 PDF documents and the Skills and Competency Catalogue lists 5792 descriptions of the skills and competencies across the organisation.

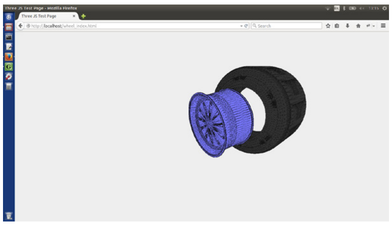
6.2 Handling a Wide Variety of Data Sources and Document Type

Wild et al. (2006) discusses a case study that demonstrates the issue of the range of file types used in engineering organisations. The study identified "*...over 250 different distinguishable document types...*". In (Hicks et al., 2010) the authors discuss a case study of the information systems in engineering SME revealing a list of 12 functional elements of IT infrastructure including Resource Planning, Manufacturing, CAD, and Product Data Management (PDM).

One of the largest challenges to business search is integrating data from across different systems and technologies and this is something that the artefact system will also need to address. The current system parses the reports and stores just the index and a link to the reports. A customised script is used to transform the text into a standardised inverted index format and stored on a separate independent MySQL database. It could be possible to expand this to different types of system on a case by case basis writing custom scripts for each case. This requires further investigation to test the effectiveness and viability of such an approach in the real world of business.



(a)



(b)

Figure 6. Handing greater volumes of POI. (a) Disappearing model leaving just a wheel and (b) exploded view.

6.3 Artefact Representations for Every Role and Multi-Faceted Search

One aspect of the artefact-based system that has not yet been addressed is the choice of artefact. Within an engineering organisation the product model may not always be the best visualisation to contextualise information, for example, it might be more appropriate to search for information viewed over the product life-cycle or the organisational structure. The Airbus Group Business Search team routinely analyse and report on their business search logs. Examples of some common search categories are *'tool' (WebEx, Microsoft Office), 'transportation' (carpool, site map), 'guidelines' (lean, leadership model) and 'career' (flexible working, family care).* Combining these with a further study of user search habits should allow the determination of the most popular context of search, and from this the best visualisation(s) for each category may be determined.

Multiple artefacts opens the possibility for a visual multi-faceted information navigation system where viewing the same information through different artefacts allows for results filtering on multiple criteria. As an example, imagine three visualisations - the product, a world map and the organisational structure (As shown in Figure 1). It is possible to filter to a particular component, tied to a particular location and a specific organisational function. This approach would allow for more rapid information navigation allowing for a level of filtering beyond the single visual representation.

6.4 Complex product structures

In addition to informatics and user challenges there are also a number of challenges concerning the inherent structure of large / complex products. These include associating information with sub-systems that span a product e.g. electronics or hydraulics, the appearance of multiple identical components and documents or data that concerns multiple sub-systems or components.

6.5 Discussion and Conclusion

This paper discussed a strategy for improving information search in large engineering organisations by proposing an artefact-based search system that re-represents and contextualises knowledge in the form of a visual model that the user manipulates and navigates through to search for information. This concept was demonstrated using a working example that visualises the end of year student reports from a past Formula Student competition in the context of a half racing car artefact. This example provided proof of concept and helped identify some key points that will need to be addressed in the development of a system for a large engineering organisation. These include techniques to handle greater volumes of data and visualising complex artefacts, indexing greater ranges of different data types from across heterogeneous systems and determining the most appropriate model given specific business/engineering requirements. As previously stated, there is a need to maximise the reuse of knowledge in the design process and provide systems that are simple and as easy as possible to use, so that designers can maximise the benefits of KM while minimising effort. The current range of off-the-shelf systems are not providing this. The artefact system project aims to show that using existing technologies and an understanding of how the engineer thinks and works, a search system can be developed that can improve the way knowledge can be disseminated across product life cycles and through the design process and so aid engineers in their day to day tasks.

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