The Inertia Problem: Implementation of a Holistic Design Support System

Nicholas Reed[1], Jim Scanlan[1], Gary Wills[1] and Steven Halliday[2]
[1]University of Southampton, UK
[2]Rolls-Royce plc, Rotherham, UK
nreed@soton.ac.uk

Abstract: This paper describes and reflects on the implementation of a Knowledge Based Holistic Design Support System – termed "HolD" – into a business environment. The paper introduces the rationale and development behind the system, a consciously different approach to traditional knowledge based systems in engineering in order to meet the requirements of a small business, producing bespoke low volume products. Typical knowledge based engineering systems rely on explicitly codified knowledge which often supports product optimisation rather than creative design activities. Such a system would provide little benefit to a business producing bespoke products. Instead, the system presented here, supports the creativity of designers through codified tacit knowledge input by designers as meta-data for past designs. The problem of individual inertia in adopting the system and sharing knowledge was approached early in the construction of the system. The steps taken to lower user barriers and encourage day-to-day use are detailed, including the design of a multi-stage input process designed to interact at key stages of users' existing processes. The immediate results after a six month trial period are presented and the results show slower than anticipated usage. In particular designers were found to be reluctant to input detailed information beyond common identifying data and did not attempt to seek information from the system. The reasons for this slower usage are discussed and possible solutions presented. The paper therefore provides industrial based evidence of the inertia encountered when implementing a knowledge system and argues that technology alone is insufficient to overcome this inertia.

Keywords: engineering design, knowledge based systems, ethnographic study, fixture and tooling, design re-use

1. Introduction

The field of Knowledge Management [KM] has grown rapidly over recent years into a widespread field of research (Lloria, 2008). Despite the proliferation of articles, empirical studies have so far been limited (Zack et al., 2009) and the relationship between knowledge management activities and business performance on an organisational level remains in debate (Darroch, 2005). The study presented here is designed to address this weakness through the implementation and evaluation of a software based Design Support System. The aim of the study was to develop a bespoke system using common technologies to best support a design team and facilitate understanding of the impact the system has on the business.

The theoretical origins of KM date back several decades, arguably to the Penrosian theory of firm growth (Penrose, 1959). Penrose espoused the idea of firm growth dynamically constrained by the availability of experienced staff resource – founding the concept of the resource-based view of the firm (later furthered by Wernerfelt, 1984). Over the following decades the idea of knowledge as a deployable resource (Machlup, 1962) and the knowledge driven economy (Bell, 1974) led to the idea of the knowledge based firm (Grant, 1996).

It is now accepted that global markets have evolved, due to increased emphasis on innovation to provide a business's competitive edge (Swan et al., 1999, Milton et al., 1999, Levy et al., 2003), knowledge has risen above the traditional advantages of capital and labour as a company's key asset (Brint, 2001). The shift in primacy is particularly important for companies in manufacturing and engineering, traditionally limited by factors of production such as materials, labour and money. It is unsurprising therefore that Knowledge Management is seen in engineering as the new step change since CAD/CAM introduction (McMahon et al., 2004). This shift is introducing new demands on companies, requiring them to efficiently manage and exploit their knowledge as effectively as they currently manage capital and labour, in order to maintain a competitive advantage and maximise their returns (Bose, 2004). This need has given rise to the field of Knowledge Management (KM).

By its very nature, Knowledge Management encompasses a wide range of issues and subjects and consequently, its definition varies depending on which perspective it is viewed from. A review over some of the key authors (Wiig, 1997, Grant, 1996, Nonaka and Takeuchi, 1995, Davenport and

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Prusak, 1998) allows at least a rough concept to be elicited as: "The management (by which it is meant the deliberate and systemised generation, organisation and application) of knowledge, either explicit or tacit, in order to provide benefit to the wider business context, where benefit is ultimately measured as business value".

Numerous studies have been completed, presenting theories and best practice approaches to Knowledge Management (Hahn and Subramani, 2000, Gruber and Russell, 1991, Hicks et al., 2002). Yet as highlighted by Lloria (2008) the majority of studies are theoretical in nature and a review of the literature returns few conclusive studies that evaluate the effects of Knowledge Management on a company. There has also been little study in support for Small to Medium Enterprises (SME's) which, arguably require as much or more support than larger companies, but have limited resources to invest (Pillania, 2008).

It is therefore believed that there is a need to study and evaluate the effects of Knowledge Management and in particular the effects of knowledge on SME's in engineering (Briggs, 2006).

2. Industrial case study

This study is supported by industrial partners who utilise a unique approach to the design and manufacture of special-to-product fixtures and tooling in the Aerospace sector. Coupling state-of-the-art laser-cutting processes with unique design and assembly methods, the company excels at providing bespoke, customer solutions in ultra-short lead times compared to traditional machined fixtures.

Fixtures and tooling are intended to provide the means for manufacture and assembly, typically supporting manufacturing operations such as drilling, welding and assembly etc. They are an unusual set of products for two reasons: unlike consumer products, aesthetics are almost irrelevant providing the fixture is functionally adequate, second fixtures feature as the "critical design-manufacturing link" (Cecil, 2001). Consequently, fixtures can rarely be produced prior to a components final design and therefore often contribute to the production part's critical path. There is therefore always a demand for shorter lead times for fixtures and tooling.

The company studied here has addresses this through a novel design method utilising the benefits of rapid manufacturing and establishing value early in the design phase. This results in highly knowledge orientated products with vastly reduced lead times. As predicted by the knowledge based economy, this shift away from the value added manufacture to value added knowledge places increasing demands on existing designers and knowledge.

This novel design approach was primarily developed by a single and highly experienced mechanical design expert. At the outset of this study, new designers had been successfully seconded into the business, however, a large quantity of knowledge capital remained as tacit knowledge and only accessible through the single technical expert. This situation not only limits future growth, but also creates vulnerability for the company with over reliance on the expert.

2.1 Business context

At the time of the study, the company had operated for approximately two years and employed six engineers and maintained a dedicated on-site manufacturing capability. The business was in a strong position, but customer demand regularly outstripped the business capacity, due primarily to the limited number of experienced design engineers.

Academically, the company represents an ideal case study to implement and evaluate the benefit of knowledge based systems to a business. The problem facing the business due to potential loss of knowledge from a retiring expert epitomises the problems faced by many companies, while the need to leverage the company knowledge is paramount as an early start-up SME producing low volume, bespoke products.

The company required a system to protect against loss of knowledge, while utilising existing knowledge to maximise design capacity. Three scenarios were identified, each with a desired response that the system should facilitate:

- 1. The technical specialist retires: Business must continue with no critical knowledge loss

- 2. A inexperienced designer joins the company: Designer should be able to design new fixtures without a high dependency on existing designers
- 3. An existing product requires improvement or repeat manufacture: Engineer should be able to re-design and re-manufacture the product without significant design iteration

To address these issues the knowledge based solution must be capable of capturing and outputting tacit knowledge, support designers and be inexpensive to implement.

3. Review of knowledge management

Knowledge is usually described as the additional contextual understanding of facts that provide the foundation for our decisions (Brazhnik, 2007). A loss or lack of knowledge relating to a particular decision can lead to unnecessary rework, increased costs from acquiring the required knowledge, or an incorrect decision to be made. Knowledge is therefore a valued commodity.

Since the term's first inception, the field of Knowledge Management has evolved substantially. A broad examination of the literature illustrates that Knowledge Management incorporates not only information systems research and business strategy but elements of psychology and sociology associated with human interaction and learning. The implication of attempting to manage human nature to the benefit of the wider business ensures that it remains a challenging subject of research.

There are a variety of approaches to Knowledge Management, in her paper Lloria reviews eight and highlights three regional differences in emphasis: European focusing on Intellectual Capital, Japanese focusing on Knowledge Creation and the Western (USA) focusing on technical capture and management (Lloria, 2008). Here the aim is to establish a proactive strategy to support knowledge re-use and insure against knowledge loss. The approach required can therefore be classified as a western approach. This approach typically utilises IT as a means to capture and codify knowledge into so called Knowledge Based Systems.

3.1 Knowledge transfer and management

The nature of knowledge has been debated throughout much of history: theories and their advocates range from Plato's dialogue "Theaetetus" distinguishing between true belief and knowledge (Plato, 360 BC) to Polanyi's concepts of tacit knowledge (Polanyi, 1958). While the philosophical debate is not relevant here, the tacit-explicit distinction forwarded by Polyani represents one of the fundamental problems facing knowledge practitioners – to what degree can knowledge be encapsulated and transferred? Polanyi argued that "we can know more than we can tell", thus not all knowledge can be written down or taught.

Both forms of knowledge (tacit and explicit) are recognised as being crucial to a company and both must be accurately managed. As a result knowledge strategies often utilise both Personalisation and Codfication approaches (McMahon et al., 2004). Practitioners have put forward frameworks to synthesise different methods into a single model managing multiple modes of knowledge conversion between explicit and tacit knowledge - most famous of which is Nonaka and Takeuchi's SECI model (Nonaka and Takeuchi, 1995). The model includes tacit-tacit conversion (socialisation), accepting that not all knowledge can be codified, but also tacit-explicit (externalisation), thereby disagreeing in part with Polyani that some tacit knowledge can be codified.

While multiple methods are preferred, Socialisation methods are not always appropriate. These methods fail to scale up if expert resource is limited and do not insure against knowledge loss in the short term. For the business studied here faced with a departing expert, the primary method was required to be a codified approach – externalising the experts tacit knowledge into a Knowledge Based System.

3.2 Knowledge based systems

There is an array of tools that fall under the classification of Knowledge Based Systems, ranging from knowledge repositories, to expert systems intended to replicate or replace human capabilities (Beckman, 1999). There have been many attempts to categorise the various different tools and techniques (Hansen et al., 1999), but in the authors opinion no method of categorisation adequately accounts for even the most common strategies developed. This is simply a consequence of the

various different characteristics that can be used to describe systems, from the level of automation employed by the system, to the degree of structure captured data is bound to.

Traditionally, systems were defined as Knowledge Based if they consisted of an inference engine and a separate knowledge base, from which the engine could determine solutions. This definition, however, was formed from the Computer Science perspective, evolving from Artificial Intelligence research stemming back to the 1950's (Sandberg, 2003).

Traditionally too, this field is where the majority of knowledge management work has occurred in engineering. A subset of Knowledge Management is termed Knowledge Based Engineering, which combines a codified rule and knowledge base with computer-aided geometric design (McMahon et al., 2004). They are generally developed using formalised knowledge of relationships to assist or automate tasks to ensure faster design or production. These systems are becoming increasingly mainstream,and CAD vendors such as UniGraphics have introduced this capability into its NX range of software. But the emphasis of these applications is typically to support automation or optimisation on non-creative design tasks, where geometry is the desired output. These 'intelligent systems' are, however, limited to the domain they have been designed for and widening the domain usually causes a decrease in capability. While suited to solving "complex, highly structured problems" (Baxter et al., 2007) these systems are simply not capable of developing novel or new product and often require a high degree of investment and capability by the users.

Recently, the distinction of Knowledge Based Systems has become blurred from the precise description above as more varied systems are developed as Knowledge Based Systems, which do not necessarily utilise inference engines. Example systems include, Communities of Practice, Knowledge Topographies and Knowledge Repositories. Generally these systems have moved to manage the less explicit knowledge, for example storing free text questions and answers in the case of the Communities of Practice.

3.3 Design reuse

Design reuse describes the application of past concepts, ideas or geometry to a new problem, minimising the time and effort required to develop the new solution. Conceptually it is easy to understand the benefit to the design process by the efficient application of design knowledge. Busby (Busby, 1998) lists four key benefits:

- Use of existing designs avoids the use of resources consumed in the original design
- It helps avoid error and uncertainty associated with new development
- It helps familiarise production staff with the design
- It helps clients maintain consistent ways of using and maintaining the product

Studies indicate that experienced designers rely heavily on past designs (Ahmed et al., 2003), yet the designers primarily rely on past designs of their own - those that they are familiar with and remember. Thus despite the potential benefits to the business, design reuse across and on an organisational level is remarkably low.

In the study conducted by Busby, he utilises anecdotal evidence to establish themes which underpin the failure of design reuse, both the failure of implementation and the failure to reuse designs when attempted. While the findings highlighted the specificity of individual cases of failure, at a high level it was possible to discern particular themes. Notably, constraints associated with the organisation and processes represented 40% of all failure cases, together with a strong influence of designer's individual preferences (and perhaps prejudices) which can preclude against reuse. Authors such as Davenport et al. (1997) and Swan et al. (1999), argue the single biggest source of inertia (or resistance) to building a successful knowledge management is from individuals. Knowledge has always been a source of influence and power, thus individuals are naturally predisposed to harbouring their specialist knowledge and the creation of a successful knowledge management project requires a fundamental change in this belief.

Busby concludes that an effective database of designs should remedy many of the issues observed. It is assumed that the database would attempt to encapsulate the rationale required (and often observed to be missing by Busby), aiding reuse. Based on the study, however, it would also need to

be established with a process for reuse to mitigate the organisational problems encountered in failure. It is this approach that is adopted in the current study.

4. Development of preliminary design system

Following the criteria described above, a system was proposed to meet two criteria:

- To capture, manage and protect existing tacit knowledge
- To reduce product lead times and improve the quality of designs by re-using this expert knowledge.

These functions would provide a tangible and valuable benefit to the business. The system must be accessible to non-experts and focus on providing knowledge throughout the entire design process – termed Holistic Support.

Existing strategies detailing frameworks and/or methodologies for Knowledge Based Systems were examined. Most relevant was Hahn's, a framework based heavily on Nonaka and Tekeuchi's model (Hahn and Subramani, 2000). These frameworks tend to assume a relatively large user population and knowledge base i.e. including expert databases (the so called 'yellow pages') and electronic discussion forums. Here, there is one expert and limited users. Traditional codified or ontological based knowledge approach would be too time consuming and costly to implement for the small company and would provide only marginal returns, given the bespoke nature of the products developed. Due to the low number of projects and designers, automated capture was also discounted as there would be an insufficient volume of material upon which to successfully data-mine (little formal documentation is currently produced).

A hybrid knowledge repository was therefore proposed which would be a semi-structured codified knowledge base but 'lighter' than intelligent systems (Reed et al., 2009).

4.1 Design system structure

The system was designed and built based on three 'cores' loosely supporting Lundvall's (1996) classification of the forms of knowledge transfer, described as: know-what, know-why and know-how. The first is a derived 'best practice' methodology to guide users through the design process. The second is the knowledge base to provide users with descriptions, rationale and details behind past designs, while also storing and aligning to archive design documents and CAD files. Finally the third section is a set of bespoke numerical tools derived to support engineers with the development of more complex or precise elements of their design.

The intention with the system was to be able to support both the design process and individual design activities, while recording and reusing the design rationale.

The methodology was derived from the experiences of the existing designers following time spent discussing past designs and observing their approaches to new designs. This resides primarily as accessible training material in the form of a design handbook, flowcharts, and presentations.

The repository is a SQL driven database storing codified information and rich media about previous designs, including the design drivers, product requirements and materials, together with relevant CAD files, photographs and video files. Following a new customer delivery, information is entered via a form relating to: the client and product requirements, the details of the design, special considerations and design experiences. A search function allows users to search and retrieve required information on existing information.

The "toolkit" provides a single-point source for theoretical-developed design tools that are specific to the technology, supporting and accelerating more involved design work such as stress and strain based calculations used by the designers.

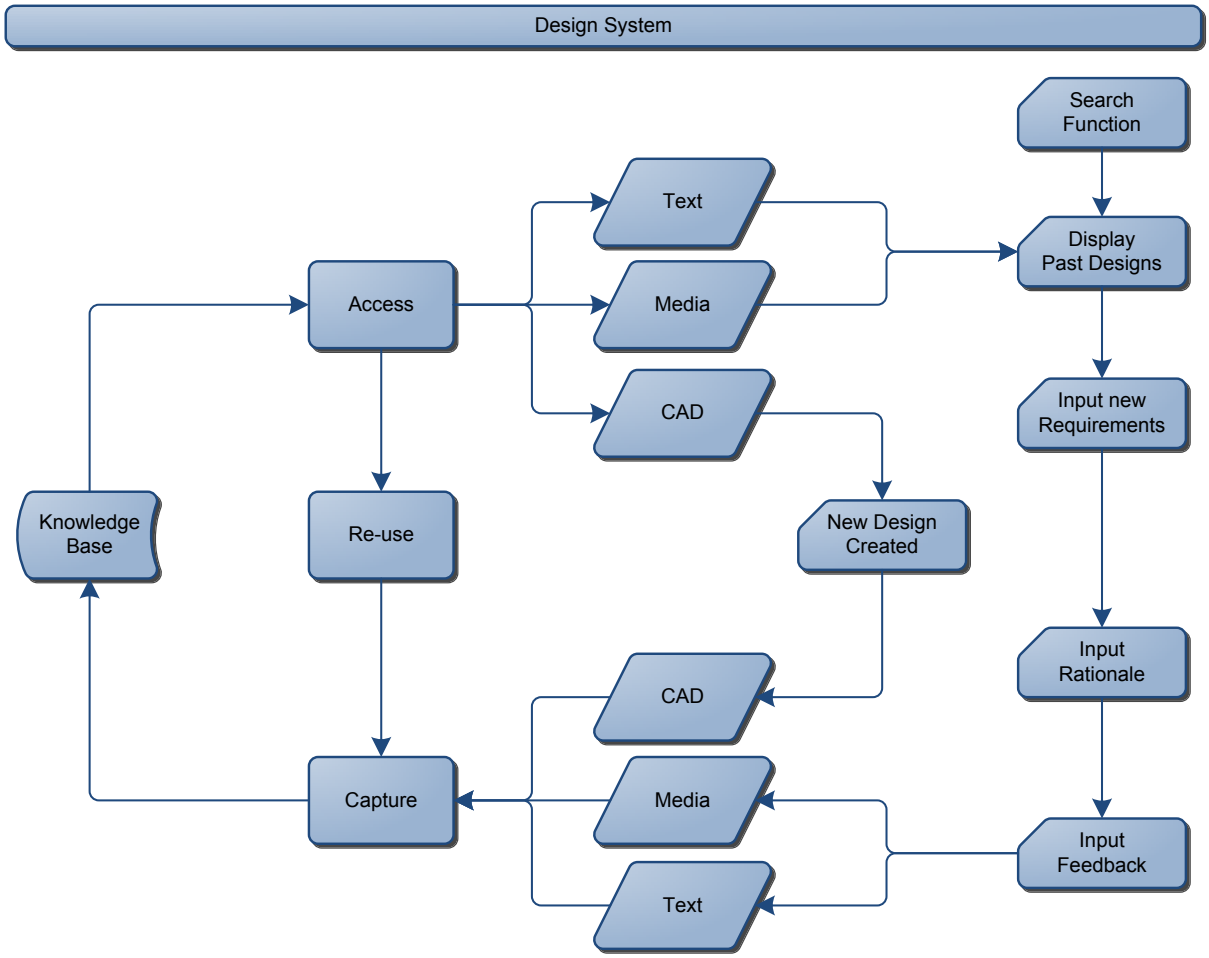

Figure 1: User interaction with the preliminary design system (moving from top to bottom)

4.2 System implementation

The system was successfully sited into the business, running on a dedicated machine and offering limited client access (the designers, however, were on a separate network and could not readily access the system without moving to the system workstation).

The system was designed as an iterative loop - that is it is populated through its use and from future knowledge generation. A variety of methods were used with the existing mechanical design expert to capture an initial mass of knowledge with which to launch the system – a requirement argued for by Hahn and Subramani (2000).

The most common and most fruitful method was 'storytelling', using semi-structured interviews with the expert, who described individual designs, together with their rationale and an overview of the main problems and solutions encountered. These interviews were recorded and codified into the knowledge base. Where appropriate, longer reports were produced and these were uploaded into the system along with the recordings of the interview, CAD files, photos and other media.

At the time of launch the system contained over 200 records, with each record holding a potential 50 fields, although, the mean completion percentage was very low at 25%. Clearly the ideal system would have more fields completed, however, the figure is a consequence of the historical nature of the knowledge (not everything was known) and the role of the researcher as the codifier – it would be hoped that when designers enter the knowledge themselves, this would be significantly higher.

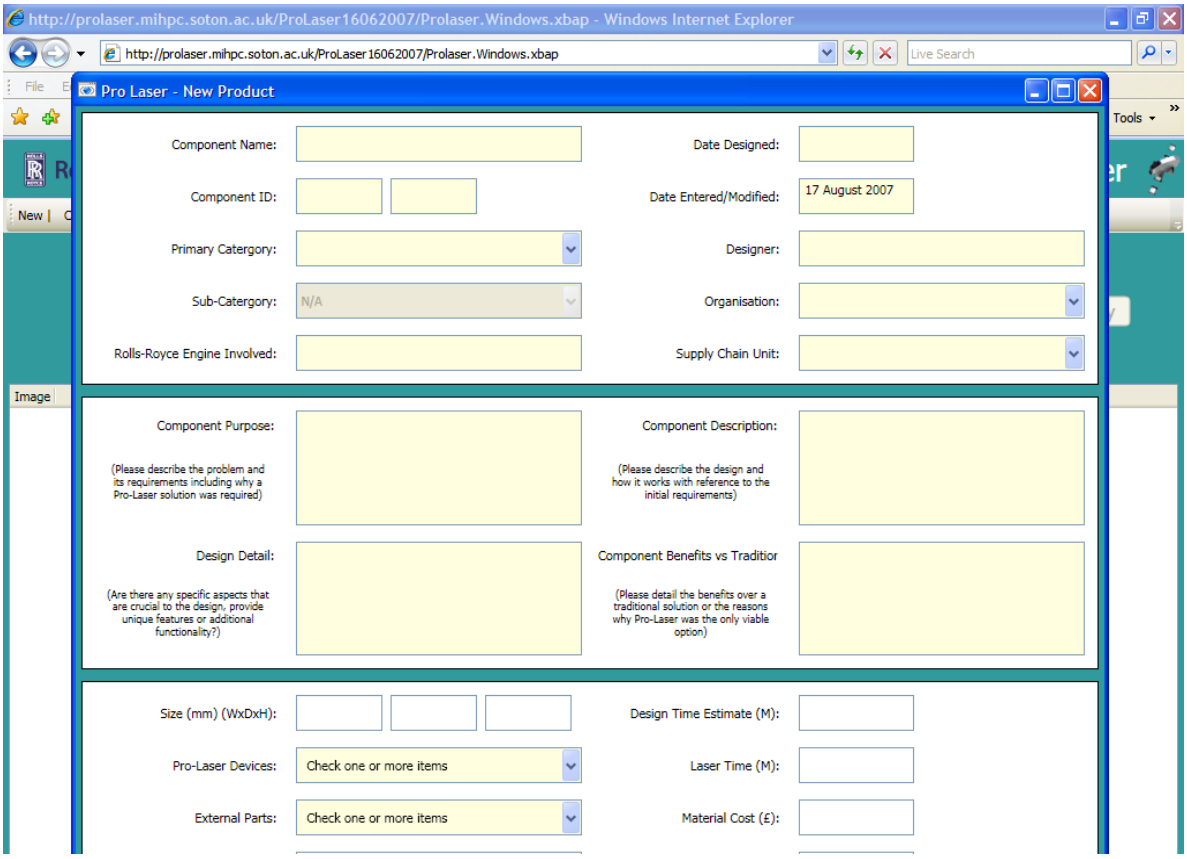

Figure 2: Knowledge repository screenshot showing an example input form

4.3 System evaluation

Following implementation of the preliminary system, observations were made as to its use and role within the workplace. In order to attempt to assess the system more quantitatively, an active controlled study (as opposed to ethnographic) was also conducted.

4.3.1 Observational results

It was clear from observations following the initial implementation of the system that the system was not in habitual use by the designers, either for inputting knowledge or searching for it. Two reasons were cited: the first was the difficulty in entering data and the second was the limited time available for designers. To assist with this, a structured approach was initiated whereby the designers set aside half an hour following the completion of any design to input the details in the system. A structured and visible job list was created within a defined office area and weekly team meetings were initiated to support a more team focused approach with population of the design system. The intention was to attempt to understand the pressures and constraints that individual designers may have and share with them the approaches that were being undertaken with the system development.

The approach was unsuccessful with designers spending too little time in the office to properly support the regular meetings and limited activity in maintaining and updating the job list. After 6 months, minimal details had been entered into the system, with the majority of these achieved through direct intervention of the author.

4.3.2 The controlled study

The controlled study was run in the middle of this period in order to determine its impact on the design process. The aim was to assess the effectiveness of the current design system, training and associated knowledge in the full development and design of a fixture.

To complete the test, engineers who were previously unfamiliar with the technology were asked to design a solution to a problem using the knowledge provided by the system. This same task was

given to existing designers and the relative approaches and designs compared. A total of five designers completed the task including the technical expert. The intention was for the unfamiliar designers to utilise the knowledge base and captured methodology to produce designs of equal standard and potentially of similar design.

All designers were given two day training on the system and the derived best practice methodology. At the end of the second day, they were presented with the design task and visited the production site for the required fixture. They were then given three days to produce a design (in CAD only) before the designs were evaluated.

The designers all completed a solution in the time designated with a variety of different designs. Structured interviews were held with all participants to obtain their feedback on the impact of the system. The interviews and observations demonstrated that all novice engineers found the knowledge repository useful in facilitating concept creation and providing the basis for new solutions and encouragingly one engineer did reuse geometry. Despite this, designers did struggle with the detailed implementation and development of their designs, often seeking more detail and depth to the knowledge. Another problem observed was in assessing the mechanical performance of the design structures. This highlighted the need for additional CAD orientated tools (such as standard design features with validated structural data) to aid design. The level of system use was also highlighted as a concern, with the majority of system use occurring primarily through the author's suggestions and designers often unsure of what to search for. Following this period, a second, modified system was proposed to meet these issues.

5. Development of HoID

Following observations and the results of the controlled test, a modification was proposed to the system. Of primary importance was the *inertia* demonstrated by individuals to populate the system and using the system to obtain knowledge. Second was the need to support the design stage with additional tools.

As discussed, prior studies have observed the inertia of individuals against knowledge sharing (Sveiby, 2001). It is often against individuals natural instincts to share knowledge openly. In the author's opinion, the observations also suggest another potential issue - that is, designers are typically highly creative and goal-focused. Their primary objective is to solve a problem through design. It should be unsurprising therefore that they find recording the rationale behind their decisions a distraction to the design process. For the system to be adopted it must therefore form part of their existing design process.

5.1 System design

The most important change was to the system structure and in particular the synthesis of the methodology with the input pages. The system was rebuilt on a dedicated server, providing users with access from their own workstations. Furthermore input is now spread over several pages corresponding to existing stages of the design process. This is intended to benefit for two reasons:

- Less knowledge is required upfront, lowering the time taken to enter information and making the task easier.
- Interaction is required at existing and natural stages of the design process. These stages should become synonymous with interaction with the system and become part of the process.

Effectively the system behaves as a gated process, with webpages (requiring input of and displaying different information) corresponding to each gate. The pages are separated as:

- *Preliminary Information*: displaying the job description, the designer associated to the project, the requirements of the client and finally any specifications relevant to the job.
- *Post-Design*: displaying information on the design solution, the rationale behind the design, calculations and tools used together with photographs, CAD drawings, video and other media.
- *Job Completion*: displaying information received following the completion of the project, modifications that were required, and feedback from the clients and designer.

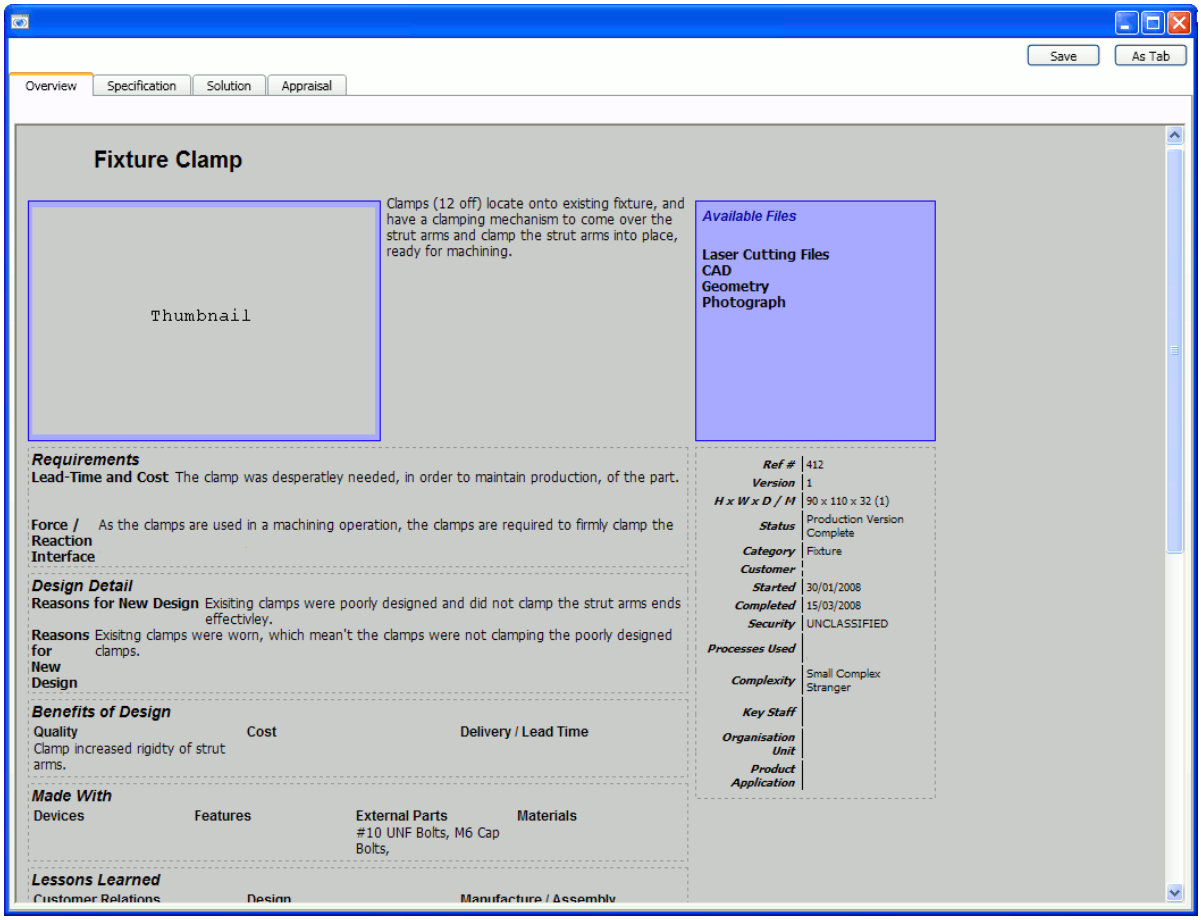

Figure 3: Example of the design system, showing the summary page of a typical fixture

5.2 System implementation

In the previous version, to encourage designers to complete records in full, input fields were made mandatory i.e. they would have to complete all fields before they could submit the information. Rather than completing the boxes in full, designers would often enter random and non-valid data in order to force the system into allowing access to subsequent forms. The updated system, removes the mandatory fields but a graphical representation of the completed fields is used instead. Commonly termed a traffic light system, three lights are shown, moving from red to amber to green as fields are complete. This gives an at-a-glance view of the completed stages and the level of knowledge held on a particular design (a crucial requirement identified by Marsh, 1997) to ensure designers aware of the information available; it also allows a better performance assessment of designer's contribution.

Following feedback from the designers using the previous version, the knowledge repository was expanded to store additional and more detailed knowledge. The system also supports wider document uploads, allowing quotes and other project reports to be accessed.

An improved search function was implemented offering users a free text search function and category based search, both allowing users to browse result pages of designs, showing the title, a thumbnail, a short description and the traffic light system. The system was launched towards the end of 2008 and existing data from the previous system was ported across to the new system with no loss of data.

5.3 System evaluation

While the previous method of testing system was useful in highlighting the benefits and deficiencies of the early version of the system, it was extremely demanding on resources. Furthermore the previous trial demonstrated that the individual behaviours of designers are far too fluid to evaluate over a short period of time. Therefore, a different approach was taken to evaluate the effect of the developed system combining longitudinal evaluation of user's interaction with detailed case studies, an adaption of Brinkerhoff's Success Case Method (Brinkerhoff, 2005). Here key projects are recorded in detail

providing anecdotal evidence of changes in learning and working practise. By combining the detailed measurements and data obtained while observing designers with the longitudinal changes in the business it was possible to observe the influence of the design system to the designer's work pattern and the wider business. The work remains ongoing, but preliminary observations have been completed.

5.4 Preliminary results

This paper reports results on the system after it had been operational for just over 6 months and several case studies have been completed. While long term conclusions will necessitate further longitudinal data, the observations to date provide for some interesting discussion. Notably, while the system has been used, the case studies indicate a slower response than hoped for. This suggests that there are other influences for the rate of the systems use that extend beyond the issues with the GUI highlighted by the previous system which contribute to individual's inertia.

There were a total of 249 entries in the system, of which 30 had been entered since the updated system was launched, during which time approximately[1] 50 projects had been undertaken. Of the 30 newly entered projects, 9 had photographs attached and one project had CAD files added. The average completion of fields by these new projects is 36%, with the highest listed as 82% and the lowest as 16%. This is a consequence of many of the entries only being completed for the first stage (customer initiation). Crucially the design and the feedback stages had not been completed for the majority of entries, lowering the value of the entries to support design reuse. Designers also did not appear to be searching for any information within the system. The following case study demonstrates exactly the situation Busby argues can be avoided.

5.4.1 Example case study

Designer A was asked for a set of 24 fixtures, functionally equivalent to a previous fixture designed by the technical expert over a year ago. The company required a new set of fixtures to support the manufacture of an updated product whose geometry varied from the original.

Designer A was made aware of the previous design and consulted the technical expert, requesting previous geometry files and discussing the project with him. An initial total of 3 hours was spent by designer A in the company of the expert.

Had the designer sought information on the system, he would have found a record of the previous entry. A video of a structured interview had been recorded of the expert and an extended document detailing the previous design had been produced. This illustrates the benefits the system could provide; it is possible that most if not all of the time spent with the expert could have been avoided and in particular the basic search and transfer of files should not be the occupation of the lead technical expert.

It is possible the designer did not consider alternative sources of knowledge. But it is more likely the designer chose what he believed to be the easiest and most profitable route to the knowledge. Yet so much knowledge could have been obtained at his desk, from a system designed specifically for its accessibility and ease of use. Why was this not a considered route? This will now be discussed.

6. Discussion

The issues of inertia and use in knowledge capture and knowledge reuse should be separated into their constituent parts: Failure to Reuse and Failure to Input.

6.1 Failure to input

As presented in the results section, designers are initiating the storage of jobs and there are several entries with a completed first page and some with minimal uploads. On the whole the knowledge required to meet the user scenarios described at the start is not being captured. Four suggestions as to why this may not be happening are:

- A lack of defined expectations

[1] This figure is dependent on when a project is considered complete however.

- Knowledge is seen as too valuable to share
- Other tasks are consciously prioritised
- Inputting information is too much of a burden
- Knowledge cannot be codified
- Confidence of work

6.1.1 Defined expectations and knowledge value

The initial two suggestions are, in the author's opinion, unlikely reasons on their own in the study presented. Firstly, there has been a high level of understanding and dialogue with the end users throughout the development of the system and in explaining the rationale behind the system. Workshops have been run in order to obtain input from the designers on how to improve the business and how best to utilise the knowledge. Second, the designers are willing and at least appear happy to share their knowledge – they have never shown unwillingness to share knowledge via other means. This would agree with the findings of Kankanhalli et al. (2005) in which the authors found that the loss of 'knowledge power' did not appear to affect knowledge codification.

6.1.2 Issues of time and effort

The third and fourth suggestions above provide interesting discussion points. At the time of HolD's implementation into the workplace, the design team underwent an annual review. The importance of the role of knowledge transfer in the organisation was made clear to the team by senior management. The team were encouraged to support the knowledge transfer programme with 30% of their time nominally aligned to this activity (of which the design system is one). This was designed as an aspiration target, in order for the designers to balance their requirements and improve their prioritisation of knowledge tasks.

From observations by the author, this is not the case. Designers spend very little of their time on knowledge related tasks and always prioritise design and manufacturing related tasks over those of knowledge transfer. It cannot be due to the burden of inputting knowledge alone, as the designers are all typically well motivated and remain committed in all other activities and tasks. It does appear true, however, that despite encouragement from management, as engineers they see notation and paperwork (and therefore knowledge transfer) as an aside to their primary role - an observation made in prior studies (Marsh, 1997). In the developing knowledge based economy, this view must change. Companies cannot afford for individuals (regardless of their ability) to operate in isolation and not support the company's knowledge base.

6.1.3 Issues affecting the codification of knowledge

As per Polayni's theory of tacit knowledge and knowing, it is possible that designers are simply not able to codify the knowledge required in the system. It would seem that the study supports this, of the 'knowledge' entered, the most common inputs were the initial specification page. This is arguably the most explicit knowledge and easily codified. Despite this, throughout the study the designers the designers were regularly encouraged to describe and document the issues they encountered and solutions they developed. This level of detail is regularly captured as part of improvement programs and customer feedback, in many organisations. Furthermore, much of the knowledge captured refers to descriptions of the product, its operation and key requirements. It is not felt that this reflects the 'un-teachable' knowledge described by Polayni (1967).

6.1.4 Designer confidence

It is possible that designers may not feel confident about sharing knowledge, not due to its valuable nature, rather due to a concern that their work may be incorrect or criticised. This is a valid argument, but inherently suggests the designers are therefore unsure about their work. The company does not currently enforce a formal interim or close-out review of every design project and feedback is generally delivered via the client after delivery. Therefore if formal review meetings were established and the designs were reviewed by a senior designer, the designer may feel more confident in sharing the design and development.

6.2 Failure to reuse

In the study here, assessing the rationale behind the inertia of designers against reuse is more difficult than that of its capture for two reasons. Firstly, as described, the knowledge base is still limited, while containing a reasonably large number of designs, many (but not all) of them are well known to the designers. Secondly, the designers themselves have been based in the company for some time and have their own history of designs. Therefore when asked why they did not search the system, the answer is typically that they knew what they were doing.

This causes two problems. Firstly, failure to search and gain from the system means the designer's will not see the benefit of the system and will be less inclined to store knowledge. Secondly, without the designers using the captured knowledge, they will not appreciate the quality of required knowledge stored, potentially resulting in irrelevant or poor knowledge being stored. Following this, four possibilities exist for the failure of knowledge reuse:

- Not invented here syndrome (unwillingness to use knowledge from others and trust)
- There is an easier route to source information
- Designers do not believe it is valuable enough
- Information obtained does not provide them with the knowledge they require

6.2.1 Not invented here syndrome

This is a recurring issue in knowledge reuse and engineering (Suresh, 2002). It can be argued that people typically prefer to work with ideas or objects they are familiar with. There may also be technical limitations when reusing geometry created by others. Here however, the intention is to present designers with examples and experiences and allow them to decide whether they are relevant and if the lessons learnt or the geometry is applicable for the new design. This has been made clear to the designers and while some geometric reuse is intended, adopting large sections of geometry were not intended unless it was a repeat product.

6.2.2 Use of other knowledge sources

As described in the case study, designers do seek information from other sources – primarily the technical expert or each other. The preference for personalisation approaches is well documented (Daft and Lengel, 1984) and has already been highlighted in this study. However, the role of the knowledge system is not to replace these interactions entirely, rather to make the majority of the discussions redundant.

It is also important that the designers understand the limitations of one–to-one interactions. With the technical expert due to retire, this 'easy' route option will not exist. Interactions with the expert currently must therefore be prioritised to those that make best use of his time and those which support the documented transfer of knowledge from the expert to the wider business. This final argument, coupled with the lack of a critical knowledge base probably corresponds to the reason behind user inertia. Rectifying this inertia will require a wider and more reliable knowledge base, but importantly, designers must perceive the knowledge base as relevant and valuable. Coupled with this should be an organisational and management led change in practise to actively encourage its use prior to interaction with the expert. Furthermore, discussions with the expert should be captured and stored on the system as part of the rationale and development of that particular project.

6.2.3 Value and content of knowledge captured

The final two suggestions are addressed by the discussion above - the designers believe the system is not valuable due to their own experience. Due to the limitations of the knowledge base this belief is likely to be true in many cases, but could be avoided with successful co-adoption. Conversely the author is not aware of any situations where designers have actually tried to find a past design and been disappointed; it is more common that they make the judgement prior to searching.

In an interesting development from the case study, when showed the codified knowledge and interview with the expert, the designer highlighted a component of the design which he had previously misunderstood. This was not a result of the expert misinforming, rather, the expert had simply not considered that the component to need explaining. Yet in the structured capture for the system, it had

been covered. It is proposed therefore that a structured knowledge capture approach may lead to greater realisation of knowledge than unstructured personalisation approaches. However, it is also acknowledged (and widely accepted) that the richness of interpersonal knowledge transfer cannot be replicated with IT systems (Daft and Lengel, 1984).

These findings therefore lead back to the SECI model and the arguments of Hertzum and Pejtersen (2000) – optimum knowledge transfer strategies need a combination of both inter personal transfer methods and IT systems. However – the lack of uptake of the system remains an issue for long term growth of the business. Regardless of the preference of designers for verbal communication, documentation and long term knowledge capture is imperative for modern businesses.

7. Conclusion

This study presents the preliminary findings from an industrial case study of a knowledge transfer programme and demonstrates that the development of a bespoke, accessible and easy to use to use system is insufficient to overcome individual inertia.

No single reason could be attributed to the reluctance of designers to implement the knowledge transfer programme described. The research here moved to optimise each of the abandonment factors identified by Jones et al. (2009): visibility, integration, co-adoption, scalability, and return on investment. Yet, while Designers did not appear to consciously avoid or oppose the programme there remained a lack of genuine shareholder engagement. Overall it is believed that the combined preference for verbal communication and the effort required to codify complex knowledge led to a poorly populated system, in turn affecting knowledge re-use.

It is therefore argued that a knowledge system's success requires an external influence (such as the implementation of formal processes and audits) to change organisational behaviour, develop new processes and encourage knowledge capture and re-use.

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