Digital information support for concept design

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This paper outlines the issues in effective utilisation of digital resources in conceptual design. Access to appropriate information acts as stimuli and can lead to better substantiated concepts. This paper addresses the issues of presenting such information in a digital form for effective use, exploring digital libraries and groupware as relevant literature areas, and argues that improved integration of these two technologies is necessary to better support the concept generation task. The development of the LauLima learning environment and digital library is consequently outlined. Despite its attempts to integrate the designers' working space and digital resources, continuing issues in library utilisation and migration of information to design concepts are highlighted through a class study. In light of this, new models of interaction to increase information use are explored.

Keywords: concept design, digital library, groupware, information use, collaboration

1. Introduction

Concept design is the process undertaken when trying to develop solutions for a given problem and covers the generation of ideas through to the selection of an embodied concept. Associated activities are often undertaken by groups in a collaborative setting, and despite the fact this is typically a fuzzy process based around sketch work and discussion, a number of formal tools and techniques have been developed to support the process (French 1985, Pugh 1991, Cross 1994, Pahl and Beitz 1995, Ulrich and Eppinger 1995). Although it has been observed that access to previous solutions can in some cases lead to fixation on particular approaches (Smith *et al.* 2008), access to appropriate information, principles, exemplars and context have been shown to be important in creating well-substantiated concepts and acting as stimuli for discussion (Benami and Jin 2002, Chuang and Chen 2008). This research is concerned with the issues of presenting such information in a digital form for effective use by the concept design team.

The digitisation of information has many advantages: it can be conveniently accessed, revised and edited easily, stored with minimal physical overheads, and communicated instantly across distance. It has been suggested that harnessing this potential can enhance creativity (Kappel and Rubenstein 1999) and that computer supported collaborative environments provide a promising innovation to facilitate teamwork. Progressive discourse interactions can take place as teams build on information stored and shared, allowing problems, design ideas and solutions to be constructed and promoting a deep understanding (Lahti *et al.* 2004). As advances in computer hardware and software continue apace, and with the exponential growth of the Internet meaning previously arcane information is now readily available, the challenge is to find effective approaches to presenting and using digital information.

For the purposes of supporting groups in conceptual design work it is not sufficient to simply recreate traditional library structures in digital form (Nicol *et al.* 2005). Navigation through hierarchical lists and exacting search dialogue boxes are unsuited to the rapid exchanges of ideas during concept design and these demands are reflected in the fact that there are a relatively limited number of digital tools used in this design phase despite the fact it is one of the most information-intensive and impactful during the product development cycle (Wang *et al.* 2002). This paper examines these specific challenges through the study of a digital library developed for design students, and subsequently suggests new approaches to integrating digital information use into the team concept design activity.

2. Literature

The literature relating to digital support for information use in concept design has been addressed under two main topic areas – Computer Supported Co-operative Work (CSCW) and Knowledge Management (KM) – as shown in Figure 1. CSCW is concerned with the effective utilisation of computer technologies to support the way people work in groups. In this context, the use of groupware (software to help groups collaborate) is the means of collaborative access and use of information, as well as communication of concepts across a common interface. KM generally relates to the capture, organisation and storing of information in a knowledge base to enhance organisational performance. Digital libraries have been identified as the most relevant technology of this field in terms of how a collection of resources can be logistically stored in digital form and accessed by the group via computers. Each of these are explored in more detail.

Figure 1: Literature relating to use of digital information in conceptual design

2.1 Computer Supported Co-operative Work (CSCW)

CSCW is an umbrella term encompassing all digital support for collaboration. It came to prominence with the increasing prevalence of computers in the 1980s, and despite often being concerned with issues relating to groupware it also addresses the broad psychological and social issues which drive team work and impinge on these support systems.

Using digital tools provides significant opportunities for distributed work, and the issues raised by this are a major area of investigation in the field. When teams are working remotely, as is often the case in today's global, multi-disciplinary design projects, access to a shared information space where teams can store, organise and share project information is even more crucial (Nicol and MacLeod 2004). However, as illustrated in Figure 2, teams working across distances using computer-based communication media can often suffer from inhibited interaction (Broadbent *et al.* 1999, Rogers and Lea 2005) and in concept design the loss of dynamism and rapid interaction makes brainstorming-type activity difficult to realise effectively.

Providing a technologically rich environment in this instance is therefore crucial to facilitate the multiple modes of communication used by designers, as described by projects such as the iLoft project at Stanford University (Milne and Winograd 2003). Expressive means such as sketching, conversation and gesture are essential for designers to communicate the subtleties of their ideas in a vivid way (Žavbi and Tavčar 2005). The vision of a completely immersive virtual environment is, however, some way off and in the meantime frameworks and approaches to manage team interaction to take account of these limitations has been a major concern (Coates *et al.* 1999, MacGregor 2002, Mark 2002). The development of mechanisms of interaction for the distributed design teams does not, however, preclude their use in co-located situations where access to digital media can augment the group activity. This research focuses on the interactions between the users and the digital support environment, with the assumption that any insights or approaches suggested based on co-located work have good potential for application to the distributed mode of working.

Figure 2: Inhibited communication in the distributed setting

2.1.1 Groupware

Groupware has been shown to provide a supportive environment for collaboration (Sclater *et al.* 2001, Nicol and MacLeod 2004). This can be particularly useful in an educational setting, as highlighted by the NetPBL (Lee and Tsai 2004) and ITCOLE (Rubens *et al.* 2005) systems developed to assist students in design project work. These systems often provide significant information resources to assist decision making and guidance for less experienced designers. In the industrial realm there have been similar attempts to co-ordinate information flows through the design process (Broadbent *et al.* 1999, Davis *et al.* 2001, Roller *et al.* 2002, Kleiner *et al.* 2003) to improve design team performance. Document-centric systems, such as the LIRÉ system (Davis *et al.* 2001) developed at Carnegie Mellon University and based on an extensive information flow analysis in order to deduce design team workflow, attempt to utilise the undoubted potential of digital information storage for quick retrieval and utilisation but do not generally address the characteristics of team interaction, particularly during specialist tasks such as concept generation.

The concept design phase has been highlighted as having a particular profile in terms of information use, communication and creativity – aspects which do not necessarily lend themselves well to digitisation with current technological limitations. There have been continuing efforts to improve the real-time immersivity of groupware (Gutwin and Greenberg 2002, Leinonen *et al.* 2005). Roy and Kodkanir (2000) describe a web-based system for conceptualisation that in addition to a digital sketch input provides link to the US Classifications patent database for convenient access to idea stimuli, with communication augmented through a shared whiteboard and chat. Another approach to creating a more immersive environment is the i-LAND system (Streitz *et al.* 1999) which is based on an integration of information and architectural spaces. Some groupware solutions for conceptual design, however, have tended to use rule-based structures to help control interactions between participants. This has primarily involved building electronic versions of existing concept design methods such as morphological charts (Huang and Mak 1999), Poolwriting (Aiken *et al.* 1996) and the KJ Method (Munemori and Nagasawa 1996) with certain benefits such as anonymity or speed of information exchange being highlighted as advantages of working in the digital mode.

Given the wide range of variables involved in the design of groupware, four suggested principles are: *maximise personal acceptance*; *minimise requirements*; *minimise constraints*; and *external integration* (Cockburn and Jones 1995). These would suggest that is important to make any groupware system as easy to use as possible, and with the flexibility to allow users to work in a way they are comfortable. This is in contrast with the very particular task-based approaches at times utilised during concept design, for example when generating ideas or evaluating concepts. It has been highlighted that many groupware solutions are not robustly evaluated (Pinelle and Gutwin 2000) and given this dichotomy it is particularly important that any system or mechanism proposed to support concept design is adequate tested to verify its usefulness in a practical setting.

2.2 Knowledge Management (KM)

KM is concerned with how knowledge can be captured and utilised to provide organisations with a competitive advantage. Often studies in the field relate to large organisations in the design and development of complex products (Fruchter and Demian 2002). In these circumstances, the expertise contained in the organisation and used in the long-term development of product lines is a critical asset to be shared and re-used effectively.

Knowledge, however, is generally regarded as being contained in the individual – when it is communicated through text, drawings or other means it becomes information. Some of the major challenges in KM are therefore less about creating knowledge – indeed in this instance the creation of knowledge through concepts is an intrinsic part of the process – but more in the capture and sharing of it (Alavi and Leidner 1999). Knowledge can also be either explicit or tacit: explicit knowledge can be conveyed through databases, books, drawings etc. (such as calculations, facts and principles), whereas tacit knowledge represents what we know but cannot easily express (such as qualities, feelings and experiences). Partly a technology issue and partly a business strategy issue, it is easy for organisations to get aspects of KM confused and attempt to solve a non-technical problem with expensive software (Tiwana 2001). It is therefore important that there is a clear understanding of the aims and objectives of any KM an organisation uses, and a sound strategy for implementation.

KM is typically orientated around knowledge items rather than mechanisms for knowledge use – Cormican and O'Sullivan (2003), for example, describe the eProduct Manager as a tool to help manage knowledge in the innovation of new products but do not address the mechanics of using this knowledge in the concept design process. In relation to conceptual design, participants are synthesising and combining available information resources, creating new conceptual ideas, and adding rationale and context. This knowledge content will be generated and reused intensely for a short period of time as the conceptual design process progresses, and then stored to be potentially re-applied in another context during future concept design activity. Understanding what information is useful, encouraging uptake, understanding how it affects subsequent design work, and capturing the rationale used are the major challenges for KM in this setting.

2.2.1 Digital Libraries (DL)

Digital libraries and digital repositories relate to the specific tools used for storing and retrieving information. Throughout the design process, large amounts of data must be managed by the design team. There remain, however, usability issues associated with the key aspects of uploading, accessing and sharing of information, and integrating these into typical design activity (Bederson 2003, Koohang and Ondracek 2005). This is reflected in the consistently low use of existing electronic resources such as subject gateways (such as EEVL) and portals (such as SMETE) (Komerath and Smith, 2002).

This can partly be attributed to the way in which digital information is commonly organised. There are several formal thesauri used by the digital library community, such as Dublin Core (Dublin Core Metadata Initiative 2009) and Inspec (Inspec 2009). These are exhaustive lists of topics, typically numbering in the hundreds, which are used as tags for items. Suitable for very large information stores, these systems rely on search terms to trace relevant material: each item is tagged with the appropriate subject terms when being entered into the library and flagged up when the user conducts a search. Entering such ‘information about information’ is known as metadata. While extremely valuable for retrieval purposes, the time and effort required to add quality metadata is problematic (Baker 2007), and this is especially pertinent during the conceptual design task given the rapid nature of communication and divergent modes of thinking employed. It is therefore necessary to carefully consider appropriate ways for participants to access and use the information repository in a way that does not inhibit them when undertaking creative design work (Csikszentmihalyi 1997).

3. Development of an integrated environment

KM and CSCW have been highlighted as the areas most relevant to the information support of conceptual design work. In each of these areas, digital libraries and groupware have been highlighted as the important technologies to facilitate effective use of digital information. Groupware solutions facilitate rich communication between team members who may be working in distributed and asynchronous modes. Digital libraries support the effective utilisation of information through efficient capture, storage and retrieval. It is of critical importance that any system takes cognisance of both the social and logistical aspects to ensure the effective use of information by groups. Therefore, the integration of functionality from these different fields is necessary.

The Department of Design, Manufacture and Engineering Management (DMEM) at the University of Strathclyde has a history of managed design environments that encompasses several research projects (Whittington and Sclater 1998, Ion *et al.* 1999, Littlejohn and Sclater 1999). This experience culminated in the JISC-NSF funded 'Digital Libraries for Global Distributed Innovative Design, Education and Teamwork' (DIDET) project (University of Strathclyde 2008). The DIDET Project was led by the University of Strathclyde, Stanford University and Olin College of Engineering and consisted of collaborators with backgrounds in: research into design team performance; pedagogical evaluation; the use of leading edge ICT in design; and research into digital libraries. The project proposed the development, implementation and use of a testbed to improve the delivery of global team-based design projects and focussed on combining the use of digital libraries with virtual design studios.

The previous consideration of these as separate tools has tended to isolate them in terms of utilisation. It was therefore decided at the outset to develop an integrated environment which, while supportive of the often ‘fuzzy’ development and informal communication that common in conceptual design work, would provide convenient access to appropriate information in an effort to make it more integral to the process. The result was LauLima (Polynesian for 'group of people working together'), a wiki-based system that was a customised version of the open-source TikiWiki groupware. LauLima aimed to provide standard groupware facilities for team communication (email, document management, shared wiki-pages) and an associated digital repository within the same virtual environment, thereby making the accessing, sharing and use of information more convenient for the team (Figure 3).

Figure 3: The integrated LauLima environment

3.1 Architecture of the LauLima system

DMEM's previous work research in collaborative support aimed to allow designers to work naturally with multi-media tools as a support, rather than insisting that work takes place in a specific manner or in specially customised areas. The LauLima system developed therefore utilised a split architecture to allow users to save, store, organise and share information in a flexible and informal way. This was referred to as the LauLima Learning Environment (LLE). In addition to this, there was a store of formal design information to search and browse called the LauLima Digital Library (LDL), which is added to with each project completed. Both these systems exist within the same environment, i.e. there is an integrated user interface and access to the library is presented as merely another function of the system. The flow of information from one domain to the other is illustrated in Figure 4.

It was felt that the distinction of formal and informal design information, while retaining the proximity of communication tools and information in the virtual environment, gave teams the most flexibility in terms of searching, storing and accessing resources. The process of moving resources from the LLE to the LDL involved staff selecting materials stored in the LLE by student teams, which already had some basic metadata applied (name, author, description), to an approval gallery. At this point, staff flagged content for inclusion in the LDL and added more metadata, particularly with regard to educational context, before items were finally approved (ensuring that Intellectual Property Rights (IPR) and Digital Rights Management (DRM) were properly taken into account) and migrated to the LDL. This model removed the reciprocity required from systems where it is necessary to entice end users to take the time to upload quality information items, but did put an onus on the department to provide staff resources for the migration of material from the LLE to the LDL.

Figure 4: LauLima system

The process of design is recognised as a social activity, both in its application and process. Concept design typically takes place in studio-based environments where people exchange information and ideas in an informal manner. DMEM's physical working environment reflects this, with student teams encouraged to undertake design work in a space where they can get support from their peers as well as teaching staff. In recent years, there has been a significant increase in the use of laptops as tools to support group work (Figure 5) and this provides an ideal format to integrate the use of digital resources into the practical desktop nature of design activity.

The LLE was the first aspect of LauLima to be implemented, and feedback in the form of polls, questionnaires, and informal comment was positive from teams who showed a high level of utilisation (Grierson *et al.* 2004). They cited strong team management benefits from using the system. It also proved popular in terms of sharing and organising design work, and creating new knowledge structures through linked team wiki pages, and there is confidence that the LLE addresses key needs of designers in relation to collaboration.

The LDL was developed and introduced after the LLE was already embedded in project work. Material, primarily student generated in the form of sketches, photographs, models and reports but also some links and external resources, was gradually added and an interface developed to allow users to browse and search for resources. This paper addresses the issues in encouraging teams to make use of these resources during concept design work.

Figure 5: The informal and social studio space

4. Class study of digital library utilisation

Although the LDL was similar in construction to other digital libraries, it benefitted from the integration with a groupware system that was responsive to the needs of design teams. Despite the documented problems in engaging undergraduate engineering students with digital repositories (Komerath and Smith 2002), it was hoped that this would be sufficient to ensure significant levels of utilisation. To examine in more detail the patterns of use during concept design, a study was carried out of a particular undergraduate design project. A student class, who were using the LLE to organise their team and document their design process, were given access to the LDL and a study was carried out in order to ascertain the levels and patterns of utilisation of the information stored in the LDL.

4.1 Format of class

The Integrating Design Project was a 6-week project where students were working in twenty teams of four. The brief was to design a fruit squeezer for use in the domestic kitchen, where students had to search for relevant information (Phase 1), develop and select a concept (Phase 2) and prototype and evaluate it (Phase 3). Teams made use of the groupware to search, store, share and organise their information and design work, and were asked to represent the development of the product using linked wiki pages (Figure 6). These inter-linked wiki pages were intended to help students develop a shared understanding of their design problem and solution.

Figure 6: Student teams documented their work on linked wiki pages

4.2 Digital library

The students were given an introduction and access to the LDL. This was through the same environment they were using to share and document their design work in the LLE. When opened, the LDL is a conventional digital library in that it is based on hierarchical lists and various metadata fields to facilitate browsing and searching. Items were categorised in a number of ways allowing users to browse by Inspec and Stanford subject terms, the class the item was harvested from, the year it was added, and the resource type (content, graphical representation, textual representation, project related). When a category was selected, it was possible to browse a set of thumbnail images and accompanying metadata to give users a clear overview of content (Figure 7). Additionally, a search interface which included features similar to those in Google's Advanced Search functions (AND, OR and NOT, search by field etc.) allowed users to target specific information. Again, thumbnail and metadata results were displayed in results lists. When items of interest were identified, users could either view them online or download them to their computer for further perusal. There were 495 items in the library, the majority of them harvested from previous student projects relating to crushing devices (can crushers and ice crushers had been previous class topics).

Figure 7: Screenshot of the LauLima digital library

5. Results

Throughout the project, all interactions with the digital library were logged by the system, allowing research and teaching staff to monitor activity. In addition, questionnaires were distributed to garner opinion on the usability and usefulness of the library at the end of the project. The results are discussed in more detail below.

5.1 Data logs

Throughout the project, student interactions with the digital library were logged by the system, allowing research and teaching staff to monitor search, browse and download activities in detail. Figure 8 illustrates the accumulated instances of each activity across all teams. There was a relatively low overall level of usage, but with considerable variance through the project. The peak of system activity was in Week 3 when information gathering was being concluded. It then dropped off as concept generation took place, and increased again towards the end of the concept development phase. The results followed the pattern of previous research in that a preference for browsing over searching was in evidence for the duration of the project (Wodehouse *et al.* 2004).

Figure 8: System logs for the 6-week project

5.2 Questionnaires

Questionnaires were distributed to garner feedback on the level usability and perceived usefulness of the library. This included factors such as preferred mode of navigation, quality of resources and ease of use.

The low level of usage by students of the digital library was reflected in the questionnaire responses. Various reasons were given, the main one being the perceived convenience of the system. “Easier” resources were cited as being more useful and more readily available, in particular Google or other web searches. These were regarded as “quicker to access” and “sufficient” for the needs of the project. This was generally not reflected in the quality of material gathered by the teams in their wiki pages, which was on the whole variable, with only a couple of teams producing excellent resource repositories. Generally, feedback reiterated that students accessed the library mainly during the research stage, with a limited number using it toward the end at the project hand-in. No-one responded that they used it in the second project phase.

The resources available on the library drew a mixed response. The students who had spent more time doing searches and browses found the material was useful and relevant to the project – there was one comment that pertinent information was there “without having to search” i.e. the material was closely related to the project being undertaken, and that being able to view exemplars provided “insight”, i.e. was useful for identifying and stimulating ideas. There were, however, observations that specific searches proved problematic, giving unexpected or unwanted results. Also, some students felt that the library contained insufficient material, and again the Internet was cited as a bigger resource where material could be found more easily. The time needed to access and use the library was also highlighted as a problem given the compressed project timescales.

6. Analysis

The results of the data logs and questionnaires were analysed and a number of key topics identified regarding use of the digital library. These included *utilisation*, *accessibility*, *navigation*, and *content*, and are addressed in turn below.

6.1 Utilisation

The relatively low overall level of utilisation of the LDL was disappointing, with observation and questionnaire responses revealing that although they generally recognised the importance of finding good quality and relevant information, students often preferred to browse the Internet rather than engage with the LDL. This may have been for a number of reasons, including the library interface, the size of the library and the nature of the items contained within it. Based on the questionnaire responses, however, students who engaged with the library found the content and breadth of material useful in their design work and the majority did acknowledge that it had advantages over web searches in convenience, relevance and the quality of resources returned.

System logs showed the library was used principally at the start of the project and again towards the end, with a significant drop when teams were engaged in concept generation work. From observation of studio sessions, the corresponding level of use of non-LDL sources (such as Google searches, textbooks, catalogues etc.) followed a similar pattern. The gathering of resources at the beginning of the project allowed students to familiarise themselves with other fruit squeezers, kitchen appliances and crushing devices in general. When moving into the conceptual phase, however, little of this information manifested itself in the designs produced. The students engaged in their conceptual design by sketching on paper, often comparing and developing ideas in conjunction with other group members, with the information gathered during their research largely neglected.

Despite the emergence of Computer Aided Industrial Design (CAID) tools to support sketchwork, particularly in areas such as the automotive industry and systematic approaches such as TRIZ (Rantanen and Domb 2002) to formally tackle problems, a paper-based, informal and collaborative approach remains common for many companies engaging in generative design thinking. In terms of integrating digital information with the designs created, a more homogenised environment where information previously gathered was presented in a useful way at the point of conceptual sketchwork, and greater ease in moving from research to conceptual modes, may facilitate more effective use of digital information. The flurry of LDL activity as the project deadline approached suggests that examples of past work were being used for comparative and reflective purposes. In terms of industry practice, such information may be applicable to project review and concept evaluation meetings when such comparisons are particularly relevant.

A number of teams with an initial resistance to using the system, and who did not reach a 'critical usage' level, tended to not use the LLE groupware element for managing their work at all, uploading only what was necessary for assessment at the end of the project. Reasons cited for this included frustration at the tedious process of having to apply metadata when upload items to the system, and difficulty in organising their file stores in a way which made it easy to refer to and share. This was disappointing, as these issues were specifically considered in the design of the LauLima architecture. It was wiki-based, giving the teams a great deal of control and flexibility in how their resources were organised, and because of the anticipated resistance to adding metadata, users were required only to add a bare minimum, with additional context added later for items selected for migration to the long-term library. These problems are similar to those faced by organisations attempting to introduce any groupware system. Conscious of the cost in terms of time and effort, if both short and long-term benefits are not obvious to the designer there is a real danger of lack of uptake. This is critical for such systems as they only become effective when they are being used across the organisation. If they are not, the result is that information is never fully integrated with the design process. Consequently, stronger mechanisms are required to encourage users to engage with the resources available to them during the concept design activity itself.

6.2 Accessibility

The common perception that the Internet, and Google in particular, was a more convenient way to access information than the LDL was perhaps confused with familiarity as when searching for specific resources there was little evidence of teams finding relevant and useful information they could use in their conceptual design work – much of it was high level information such as catalogues and on-line retailers. It was noticeable that there was a general failure to make use of any of Google's advanced search features to optimise their searches. The LDL search facility was deliberately designed with these advanced search features on the main interface to encourage their use. It was found, however, that the number of options served to make the page intimidating and actually led to less use of the library. In light of this, a strategy similar to Google's, i.e. providing a basic search as default and calling up more advanced features as required, was considered more appropriate. The LDL's browse feature, too, had accessibility issues. It contained a high number of categories and terminologies which were not very transparent, requiring further investigation to reveal content. A better approach may be to have a flatter branch structure with fewer categories and simpler terms, and relying on the effective presentation of summary metadata to ensure effective browsing.

6.3 Navigation

When using the system, browse was favoured over the search feature. This could be attributed to a lack of knowledge of information literacy and searching strategies, with browsing preferred to having to identify and combine appropriate search terms. Parallels can also be drawn to the visual and non-linear nature of creative design work – browsing through category lists and thumbnails is a convenient way to view diverse material and can spark new directions of thinking. Another contributing factor was the relatively small size of the library, meaning it remained feasible to browse through lists rather than conduct a search. Although there were no statistics for the particular types of browse activity, general observation revealed the resource type categorisation to be the most useful. Items were described in a practical, descriptive way (with terms such as 'chart' and 'animation') and grouped into only four main categories whereas the standard thesauri had extremely long and specific lists which were somewhat intimidating. For larger digital collections, the granularity offered by such approaches is necessary, but in this context with a smaller and more specialised library they did not perform optimally. As the project progressed, it was assumed that students would search for the more precise, often technical, information required during design embodiment and detailing. Instead, proportion of browse to search instances remained fairly constant. This indicates that content does not necessarily have a strong effect on the method of retrieval used, but the limited data set means this issue would benefit from further investigation.

6.4 Content

As the library was mainly populated with material from previous projects (topics included can and ice crushers) the bulk of it was closely related to crushing devices, and although this ensured the relevancy of the material in the library it was not enough in itself to entice significant utilisation. The user-generated material in the library was chosen to encourage learning from examples, by mistakes and by building on existing ideas. In an organisational setting the value of specialised resources developed over a period of time can be expected to support brand consistency and product line continuity. In the development of concepts in this setting, however, it was seldom used. During this activity, designers require inspiration to spur creative thinking, but also a knowledge base to allow informed speculation in the area of development. Although the library contained a mix of these different materials, much of it was associated with the conceptual work of previous students. There was a sense of resistance to accessing material which perhaps reflected a desire to demonstrate original thinking, and that looking at others' ideas would detract rather than stimulate this. It may be necessary to consider other formats of presentation of such material – it was shown to be beneficial in the latter stages of the project as exemplars for benchmarking work prior to submission but may not be suited to acting as neutral stimuli or technical references for generative or developmental design work. The size of the library, at almost 500 items, was a significant but not exhaustive resource, and users highlighted that the Internet afforded far more expansive searching and browsing opportunities. This is countered by the fact that the library provided richer resources which were more easily located but the flexibility of using web browsers is appealing to the expansive mindset adopted through informal, collaborative conceptual design work. Digital libraries for such applications should therefore be large enough to be considered suitable for this type of research or facilitate the acquisition of new information from external sources.

6.5 Conclusions of study

The study highlighted a number of issues regarding the use of digital information through the early stages of the design process by a student cohort. Although it took place in a controlled educational setting and did not address more systematic and hardware-enabled scenarios which may be employed (in larger organisations particularly), it did replicate an informal, team-based approach to concept design work that is common in many industrial situations. In general the digital library was underused, with time, convenience and perceived usefulness being the biggest obstacles to use, and Internet searches instead being the preferred mode of research. Students who engaged with the library, however, found its content and relevance useful, and there was a broad appreciation for the importance of good information to the design process. Despite this, observation showed that overall peaks and troughs of information utilisation through the design project applied to both Internet searches and LDL use, and that there was a general lack of direct utilisation of this information in the concept design work produced. This suggests that stronger mechanisms are required to encourage users to engage with digital resources during conceptual design work, and that the presentation of information in a more sympathetic way could result in better substantiated design concepts.

7. Developing interaction with information

This paper has outlined the importance of an effective shared information resource in supporting conceptual design. The development of the LauLima Digital Library as part of an integrated design environment and subsequent evaluation of its use in project work has, however, illustrated continuing problems regarding user engagement with digital resources during concept design. To address this, it is necessary to consider new ways to increase the team engagement with information during the design activity. If the groupware environment is considered as the interface through which digital resources are accessed, then the research problem can be summarised, as shown in Figure 9, as trying to improve mechanisms to bring the activity and information together more effectively. Specific approaches to structuring the library format and interaction mechanics are outlined below.

Figure 9: Integrated approach to digital support for conceptual design

7.1 Library configuration

Although the LauLima system aimed to integrate a highly contextualised digital library within the working groupware environment, the temptation remained for users conduct quick Google searches when they required an item of information. To understand why this is, it is necessary to consider the nature and role of the digital library. Although the Internet provides access to a vast amount of material it is completely unstructured, and despite the consequent ineffectiveness of many high-level search engine searches it appeals to users in its flexibility and freedom to explore. On the other hand, digital information systems have largely emerged from the field of librarianship rather than design, and the typical hierarchical lists and search interfaces do not lend themselves to creating an explorative experience. Witten and Bainbridge (2002) recognise this issue when they discuss the "in"-ness of a library as being critical: since digital libraries do not have a physical structure some notion of boundary is required so that it envelops the user in an intellectual if not a physical sense. Rather than considering digital libraries to be representations of traditional library structures, it may be appropriate to consider them "discrete small-scale projects which embody different approaches to information storage and manipulation, but which are linked together to form a wider resource" (Carpenter *et al.* 1998). This is essentially the same model used by the Internet – when specific pages are identified as being particularly useful they can then easily be bookmarked and used consistently. Given the focussed nature of concept design, it may be that a series of smaller, more specialised information resources selected as appropriate for the particular design context would be more effective in supporting the particular interaction structures of the team.

7.2 Retrieval strategies

Retrieval strategies also have a strong bearing on library format. The results of the class study showed a general preference for browsing for information sources, and that when searching for information a quick Google search was the preferred method. Browsing is the most effective way to navigate relatively small file numbers – the speed of the human eye allows information to be processed quickly, so providing that different resources are clearly identified the required resources can be quickly located. For very large resources, however, it this is not feasible and search tools are necessary. In light of the class study, it would seem appropriate to keep any search mechanism as simple as possible, i.e. similar to Google's minimalist approach, and assume that advanced searching facilities will not be employed. An alternative approach would be to employ Information Literacy support prior and during the session to ensure users were aware of strategies and knowledge of how to construct effective searches.

7.3 Visual presentation

It may be that the analogy of a library is in fact not appropriate for the concept design environment at all: sketching is a fundamental means for the designer to internally develop ideas as well as to communicate them with others (Schutze *et al.* 2003). Given its key role in the concept design process, it must have a major bearing on the information use of the team. Rather than filing information items in a systematic way, having them out in the open in the same environment as the groupware or sharing element of the system may be a more appropriate approach to allow the information to act freely as stimuli when ideas are being created. An analogy akin to a designer's sketchbook may be more applicable, with annotation, notes and ideas marked directly onto or alongside the items of information which have been used to inspire or inform a particular concept. The LauLima system went some way towards this by having the library in proximity to the environment of use, but this requires further extension to provide a more vivid interface that is actually part of the concept design process rather than a separate entity which must consciously be visited.

7.4 Linking and highlighting items

The tactile quality of physical resources such as models allows them to be effectively used as prompts for explorative discussions, often acting as the centrepiece as they are touched, operated and manipulated. This is not easily replicated in the digital environment but if information resources are made vivid, with their benefits explicit, it may lead to a greater willingness to engage through the digital interface. To help achieve this, forms of tagging or tracing could be used to highlight the applications and uses of resources. If, for example, a particular image of a relevant mechanism inspires a concept, the designer can then tag or link the subsequent sketch with the relevant stimulus. This means that each time someone refers to this concept, the corresponding resource is also highlighted, thereby encouraging others to explore how it was used and to exploit it themselves. This could be extended to recommending resources to others, or requiring resources to be used in particular conceptual activities. This potentially creates a more dynamic sharing and creating environment, and a higher turnover of information. Such proscriptive mechanics must be carefully considered – those which inhibit the 'flow' of concept design work are unsatisfactory.

7.5 Use of requirements

Another way to structure the interaction with the library is using the requirements provided by the design brief or Product Design Specification (PDS) document. These are constraints on the design space, providing clear limits on various design criteria such as product size, life, functionality etc. Rather than being viewed as potential inhibitors to creativity, they could instead be utilised to guide resource searches by topic, providing key words and terms for information searches. Alternatively, they could be used in conjunction with tools such as concept maps (Tergan 2005) to build an overview of the information field and a strategy for acquiring sources. Collecting information resources according to designated topics will undoubtedly influence the concepts produced – if a team has access to information on particular materials, for example, it is likely they will use them in the concepts they develop – and this can provide a means to ensure that the design team covers a range of criteria during their conceptualisation work rather than focussing on one narrow aspect. Additionally, the requirements could be used to ensure that certain pre-prepared material was available to the team as they undertake the concept design work, for example the term 'ergonomics' could activate an automatic link to sources such as databases of anthropometrics, images of the body or ergonomically designed products, allowing a tailored library to be configured for use in the concept design work.

7.6 Concurrent search and design

Context is critical to the supporting information library. For a resource to be effective to support concept development work, it must contain an information set specifically tailored for the problem. Rather than having an extremely large information resource requiring significant effort to retrieve the relevant information each time the process begins, an alternative approach may be to find information *as part* of the concept design process. The majority of design process models specify external searching as a necessary part of the design process, but is usually carried out in isolation. Mechanisms to integrate phases of creative design work with exploratory information searching tasks could be utilised, the concurrent nature of the activities helping to ensure that the information being retrieved was relevant to the task at hand, and the information handling at the very point of concept generation compelling its use in the creation of new ideas. This mixed mode of thinking is contrary to the consistently divergent attitude expected during purely generative tools such as brainstorming. These personality-driven approaches, however, been shown as impractical in current digital environments and such an alternative could offer significant benefits in terms of use of information and controlled communication patterns, potentially focussing attention more effectively on the information and ideas created by the group.

8. Conclusions

This paper has outlined the importance of digital information systems to conceptual design work. A new integrated groupware and digital library has been presented, and the results of a class study outlined. Continued problems with ensuring adequate interaction during the concept design activity have been highlighted, along with suggested strategies to improve this situation. It is anticipated that future research will examine how these strategies can be embodied in the design of new tools and interfaces to support more effective use of digital resources by concept design teams.

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