INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

DIGITAL INFORMATION SUPPORT FOR DISTRIBUTED CONCEPT DESIGN TEAMS

A. J. Wodehouse, A. P. Conway and W. J. Ion
University of Strathclyde
Department of Design, Manufacture and Engineering Management (DMEM)

ABSTRACT
Distributed design teams are now commonplace in today's global economy. Although the management and control of detailed design information has been addressed through the widespread use of CAD, there are fewer tools to assist the design team in the management and use of information during the concept generation and design phase. During concept design, a large amount of information is retrieved, generated and used amongst the team, and the decisions made have a major impact on the direction of the product development project. This paper examines the current digital tools available to support the information needs of design teams during concept design, comprising both groupware and digital library solutions. It then summarises a set of scenarios taking place to discern communication patterns amongst a group of designers during the concept design task. Finally, conclusions are drawn on possible directions for future technological support, in terms of adapting these technologies to better support the needs of design teams.

Keywords: Information, digital libraries, groupware, concept design

1 INTRODUCTION
As we move towards a more global economy, the distributed product development team has become more commonplace. This means that effective use of information is essential for the success of the design process. This is especially true in the concept design phase: for design engineers, finding and handling large amounts of information in developing new ideas can be problematic [1, 2]. For example when a design consultancy takes on a new project, the design team is required to quickly grasp the pertinent subject about which they may have no prior specialised knowledge. This is, however, crucial if they are to create well-substantiated concepts. The approach of consultancies and other product development teams is to have a robust approach to the design task which can applied in any given field. This requires vigorous interaction with relevant design information in order to immerse themselves in the problem. The approach to this varies from organisation to organisation and may depend on cultural, social and technological factors. As today's product development projects rapidly become more global in nature, the mechanisms by which the design team interacts with, communicates and handles information are even more crucial. The same processes and mechanisms which work well in a co-located, synchronous environment, which is usually the case for conceptual design work, may not be ample for distributed and asynchronous work across distance. Bridging cultural, temporal and technological divides is a key problem and the interactions of the design team during the concept development task must be adapted accordingly.

1.1 Background
The concept design stage is when there is the largest variation and most rapid communication of ideas amongst the design team. This takes place in an informal and dynamic situation, typically with people undertaking brainstorming sessions, sketching ideas, and using whatever resources and inspiration come to hand. This is the most divergent part of the design process, when a broad range of ideas are welcomed, allowing the design team to choose from a large variety of ideas. Divergent work, of course, takes place throughout the design process as alternatives and variants are developed, right through the detail design phase. It is in this first concept design phase, however, when the concentration of ideas is most intense. Digital tools are potentially a powerful way to store, organise

and retrieve large volumes of information. Designing methods of interaction to do this in the informal, idea generation scenario demands that we reconsider current interfaces and ways of working with the tools to fully realise their power.

In the global economy, most large product development projects are distributed in nature. As this process continues, we can expect many design teams to have members scattered across countries, cultures and time zones. Closer integration means that this interaction is not just happening at a design phase level but at the task level, i.e. team members working globally in parallel on specific design tasks rather than a design centre simply sending files for manufacture. It will therefore become crucial for distributed team members to be able to undertake specific tasks like idea generation. Digital information again plays a crucial role in this new paradigm due to its power to rapidly communicate information and ideas over distance.

Currently, there are a large number of tools to control the flow of information at the detailed design stages, e.g. Knowledge Management (KM) systems for large-scale development projects such as aeroplanes and ships, and Product Data Management (PDM) systems to carefully control changes and amendments to CAD data, but far fewer which address the needs of design teams at the conceptual design stage [3]. Conversely, as illustrated in Figure 1, this is the stage at which decisions made by the team have the greatest impact on the direction of the project. For this reason, there is scope to better understand and support the needs of distribute design teams undertaking the conceptual task using digital technologies.

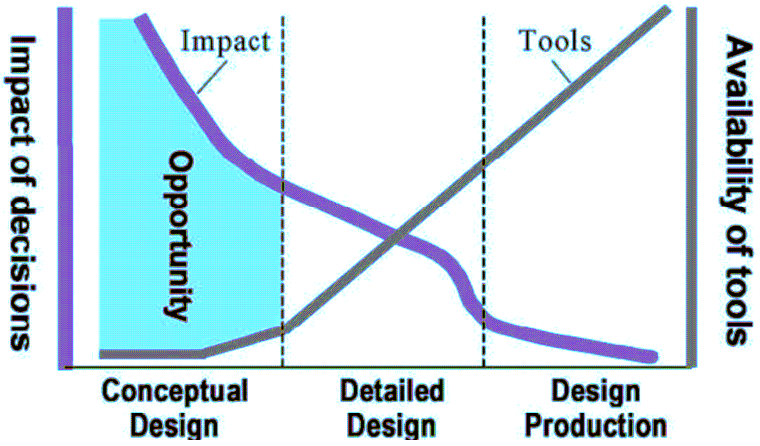

Figure 1. Impact of decisions vs. computer tools (Wang et al., 2002)

The tools which do exist for distributed teams to find, share and use information in an informal manner can be considered in terms of digital libraries and groupware. Existing digital libraries have developed from the field of librarianship and largely retain the traditional use of hierarchical lists and structures. The formality of these interfaces means they are not necessarily orientated to the needs of designers [4, 5] particularly during the idea generation or concept design phase, when they may want to work in a more rapid, responsive and unstructured way. During brainstorming or idea generation sessions in particular, designers are reluctant to interrupt their 'flow' [6] to do laborious searches for pertinent information. Rather, they want to be able to call up items to verify designs, provide inspiration, compare features and so on. There is currently a notoriously low use of existing electronic resources such as subject gateways and portals despite significant investment in these technologies. This is a particular issue when a distributed design team relies on a web-based interface to manage and communicate essential design information. Groupware is software which allows groups of people to collaborate through tools like email, forums, chat and shared folders. Many have begun to introduce tools like shared whiteboards to help more visual communication of ideas, but access to information stores must come from elsewhere and the process of sharing information typically relies on laborious uploading and downloading of files. Digital tools can potentially combine the speed and convenience of storing and accessing information with advanced communication methods, to create a virtual environment rich in information and more suited to the 'messy' nature of the concept design task.

1.2 Research Framework

The objective of this research is to create something more dynamic for the distributed design team, as shown in Figure 1. By isolating the concept design task, the Product Design Specification (PDS) is considered the starting point for the work, providing a set of rules and constraints for the team to work with. A set of synthesised ideas, or concepts, is the output at the end of the task. Information is drawn into the environment as the team acquires relevant resources and knowledge to help with the synthesis of the ideas. This is termed 'on the fly' information, as the information sought depends on the ideas being generated. The information source has been limited to information the company would have prepared prior to the concept design task, i.e. market data, competition, previous product knowledge, relevant technologies and so on, and has been indicated by a filing cabinet. This is the equivalent of the digital library store of resources. This same information source would obviously have been used in the formation of the PDS before the design task begins, and the PDS has therefore been designated 'pre-prepared' information. The PDS can be assumed to provide constraints and the information stimulus to the concept design task. Although external information could be drawn into the scenario, particularly if it is regarded as a longer-term or ongoing task, this research focuses on the interaction between team members (the question mark in Figure 2) and their use of the PDS and digital library as sources of information, and therefore external information has been excluded from the model. By enhancing the use of digital information in the distributed scenario, it is hoped not only to improve distributed concept design work, but to provide a model which can improve on the co-located situation.

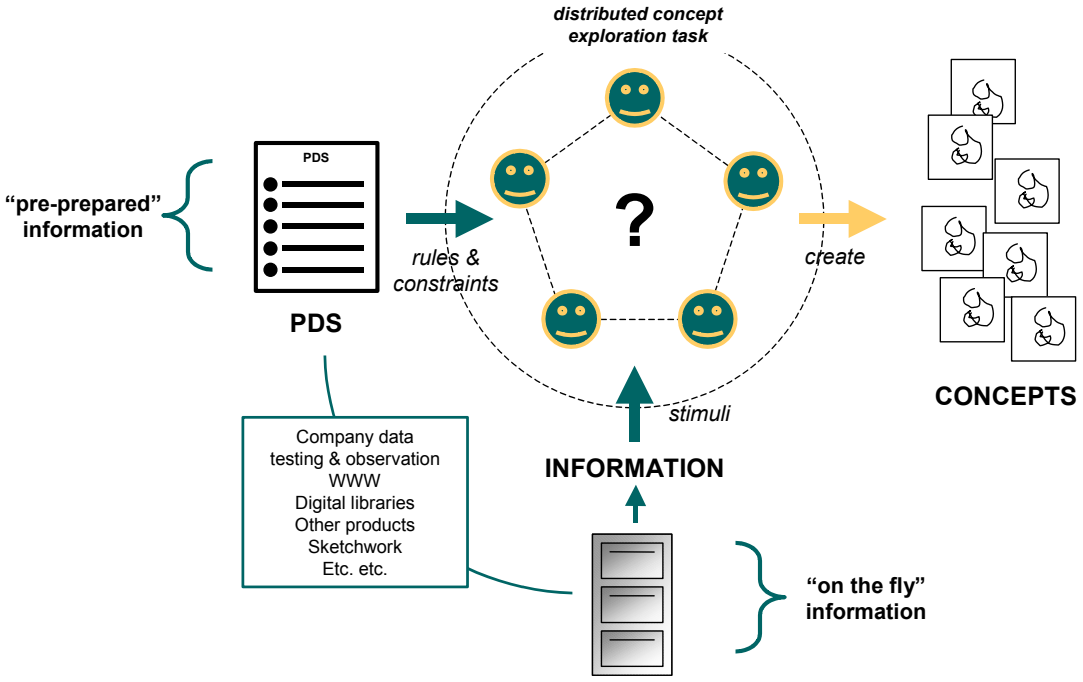

Figure 2. Overview of scenario

2 COMBINING GROUPWARE AND DIGITAL LIBRARIES

The process of finding and sharing information across a team is addressed by two categories of tools: digital libraries and groupware. Digital libraries are where information is uploaded, stored and retrieved. A large number of digital libraries and repositories have been developed for engineering designers. Many of these existing resources, however, suffer from low levels of utilisation [7]. In recent years, systems such as Web-CADET [8] and ITCOLE [9] have recognised some of the problems regarding usage of such digital repositories, and have tried to enhance their transparency. From a product data perspective, systems such as the COLIBRI system have attempted to share design constraints across a team based on product CAD data [10]. There remain, however, usability issues associated with the key aspects of uploading, accessing and sharing of information [11]. By isolating

the concept design task, it is hoped to identify how interaction with design information can be optimised.

Groupware refers to software designed to allow groups of people to collaborate towards completing a shared task or goal. The technology is primarily focussed on communication through email, forums, chat and shared spaces in order to co-operate and solve problems. Groupware potentially uses the power of digital communications to reduce project time and cost, through the more efficient management and organisation of the team and associated project information. The success of groupware is more unpredictable than single-user programs since it depends on a collective 'buy in' from the group using it. Computer Supported Co-ordinated Work (CSCW) tries to examine and formalise theoretical ways for teams to interact using such groupware technologies. Many current packages, however, are still technology led, in the sense that a group of communication facilities (email, video conference, chat, forum) are grouped together without much consideration of the working practices and preferences of the user group [12]. This includes the fact that most systems are either set up from a single user perspective, i.e. a project manager organising the team, or does not take into account the status, power and interest issues which can be a negative of collaboration.

2.1 Towards an integrated approach

The Distributed, Innovative Design, Education and Teamwork (DIDET) project at the University of Strathclyde has attempted to create a more integrated and sustainable digital environment for teams undertaking design work [13]. The system, called LauLima (Polynesian for 'a group of people working together') is a Wiki-based system which combines both a groupware (LauLima Learning Environment, LLE) and digital library (LauLima Digital Library, LDL) element to support design teams (Fig. 3). Although the LLE and the LDL components can be considered discrete elements of LauLima, they are designed to be interdependent and a workflow procedure has been developed that inter-links them. Staff in the academic department harvest the most useful resources from students' LLE workspaces and submit these for inclusion in the LDL: 'usefulness' in this context refers to 'potential for reuse'. This selection is subject to a final approval stage where an information specialist checks the resources for quality and legality and adds additional metadata. In turn, resources also move from the LDL to the LLE when students retrieve them to inform their design projects. This creates a workflow 'loop' of creation, use, storage and reuse, and the proximity of the two systems within the same virtual environment helps to aid with integration and accessibility of information.

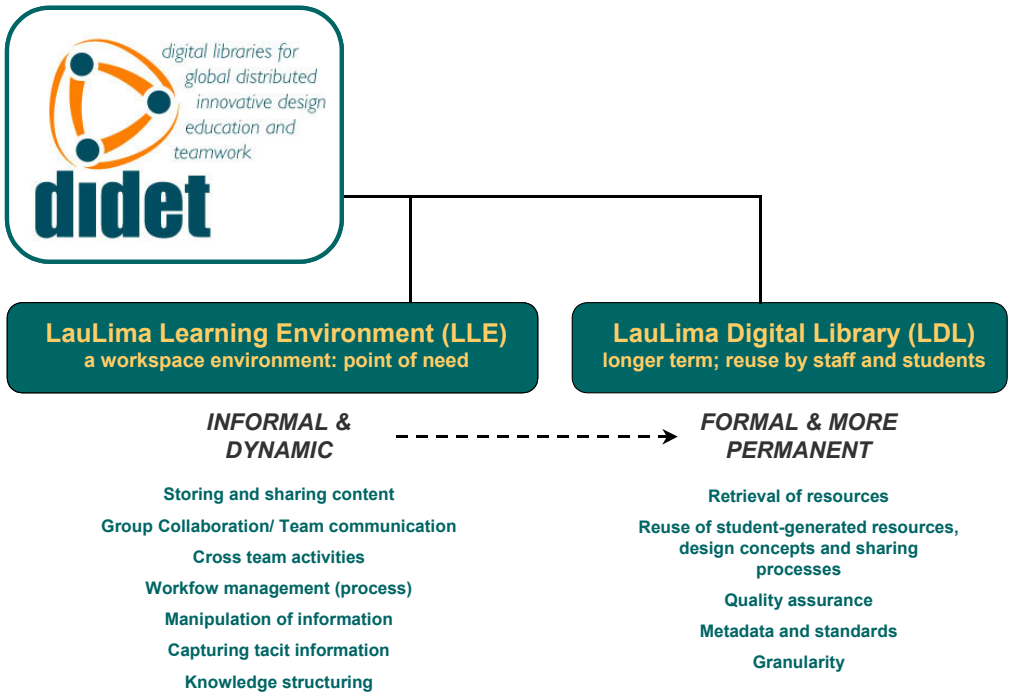

Figure 3. Architecture of the LauLima system

The LauLima system has gone some way to making the concept of a library more organic, by allowing users to upload content and see past examples. It still depends, however, on a librarian to check and approve, for legal reasons, submitted items for addition to the library. This is of limited use when a team is finding information and creating ideas in one fast-moving session. Additionally, uploading an item to LauLima, as with the majority of formal digital libraries, requires several fields of metadata to be entered, such as title, keyword, description and so on. By removing unnecessary barriers, it may be possible to make this process quicker, which is certainly necessary to ensure the flow of concept design is not interrupted. Simply increasing the proximity of the two components of the system is not enough to ensure its sustained use: for a specific, dynamic task such as concept generation, it is necessary to make a highly integrated environment, more along the lines of a computer game or other integrated system. This requires the patterns of interaction of the concept design task to be more clearly understood in order to design a model of interaction with the information and amongst the team which will allow the creation of well-substantiated concepts.

3 FOCUSSING ON CONCEPT DESIGN

Having identified the concept design task as the focus of the work, and responsive interaction with the information sources a necessity for its success, a design scenario was created to identify the patterns of resource use and interaction amongst the design team undertaking this type of work. The scenario was designed using a simplified version of the research framework, as illustrated in Figure 4. The concept design task is considered in isolation as the synthesis of concepts, with a PDS and resources the two primary inputs. For the purposes of the scenario, a detailed brief was provided, which assumes the role of the PDS for this purpose. The object was then to monitor two elements:

- Patterns of team interaction
- Use of resources

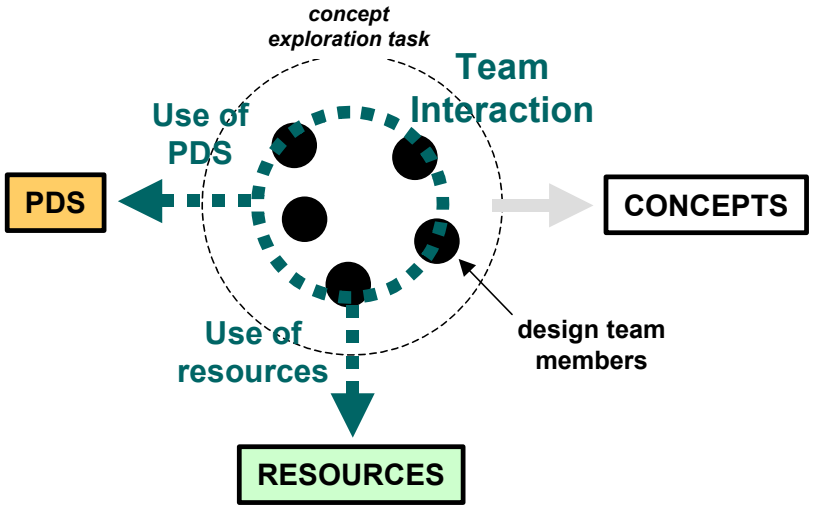

Figure 4. Concept design task

3.1 Set-up

Four designers (plus chairperson) were asked to develop concepts for a coffee cup holder. They were given 30 minutes to read a design brief, develop ideas and identify one for further development. The meeting was videotaped with two cameras, one to capture the general conversation, including body language and other conversational idiosyncrasies, and one focused on the table where sketches were done and various resources picked up and used. A set of resources was made available to the team, including the design brief, existing products, conceptual sketches, and prototype designs.

3.2 Analysis

The videotapes were transcribed, and the Transcript Coding Scheme (TCS) as described by Huet [14], a discourse analysis method, used as a basis for analyzing the video footage. This involves identifying

for the transcribed meeting: Intervention type; Exchange role; Information type; Primary Media type; Agenda Item. It was necessary to go back through the video in order to identify the Primary Media used during discussion, as this was not revealed through the transcripts alone. The other category which was of particular interest was Information type. This relates to the types of product life-cycle information, i.e. whether it is product, process, resource or externally related. The results of this category can help with the correlation between the thrust of the design meeting and what information is being utilized. In addition to this, Badke-Schaub et al. [15] have developed a protocol to identify 'critical situations' in design meetings based on 5 variations: Goal-analysis and goal-decisions; Information and solution search; Analysis of solutions and decision-making; Disturbance-management; Conflict-management. This was applied to the transcribed meetings in order to identify the key passages during the design meetings.

Work is continuing on analysing the scenario results, including sessions with and without resources. However, Figure 5 illustrates the TCS and critical situation analysis for the first 10 minutes the session. Time is shown along the bottom row of the table, indicating when each interaction took place. Information role is shown in the next row up. It can be seen that the majority of the time was taken with debate and clarification, with sporadic management and clarification interactions taking place. The next row up shows the media which were used during these interactions. Use of the design brief is shown in orange, use of other resources in green. The team continually referred to the brief at the beginning of the exercise, while they familarised themselves with the task. These are associated with a number of clarification interactions, when people were verifying that they had a shared understanding of the problem. A period of resource use can then be seen. This was the subject of some clarification as they discussed the designs, and was followed by a period of exploration, building on the ideas thrown up by the designs. The brief and resources are both then used at intervals as the team continues to debate what they are trying to achieve in the task. Since this is the first 10 minutes of the meeting, the pattern of clarification, then exploration is to be expected. It is necessary to assess the full 30 minute session in its totality to identify clear patterns of resource and team interaction. The initial findings, however, suggest a number of issues for exploration.

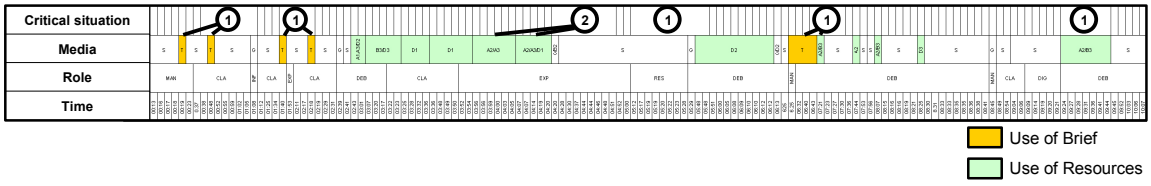

Figure 5. Use of resources in concept design

3.2.1 Patterns of interaction

There were 6 critical situations identified in the analysed segment of the design meeting. Of these, 5 were related to Goal-analysis and 1 to Information search, and only 1 of these situations (at 07:30) resulted in a critical decision. It would be desirable to identify clear linkages between particular information types and the critical situations which arise, and Figure 5 has attempted to show how the resources used were relevant to particular decisions. From this small segment of time, however, it is difficult to clearly discern the relationship between the two. The majority of the critical situations being Goal-analysis, it is unsurprising that the brief plays an important part in reaching a resolution of the requirements. The one critical decision made was also linked to the use of this brief. These situations are also consistent with the Clarification interactions described under the Information role category. A lack of consistent idea generation work, however, makes it difficult to draw conclusions on the use of resources during the Exploration interactions. One critical situations was linked with a consistent use of resources, but this is insufficient to give any insight to patterns of use. It is hoped that clear patterns will be revealed through further studies. It should be noted that a major form of design communication which was not used during this short segment is sketching. Sketching is an important means for the designer to think through ideas as well as communicating information with other members of the team. It is anticipated this will have a major bearing on the interactions of the team. With the full analysis of the design meetings complete, a strategy of tracing back from the critical decisions and situations, as indicated by the red lines in Figure 5, the information used and the

interaction categories, with reveal the most appropriate and useful resources to be made available to the team, and at what frequency they are likely to be used.

3.2.2 Use of resources

The brief was used consistently through the meeting as the team reached a shared understanding of the design requirements. Certain words proved triggers for the team, as they debated and clarified what they meant. These tended to lead to critical situations where there was an agreement on terminology or design direction. When the other design stimuli were used, the team moved into a more exploratory mode. Although a level of familiarisation was still taking place, the resources provided a forum in which to discuss thoughts and experiences of similar products – for example, people began to discuss frustrations with coffee cup designs and atypical use of coffee cup holders. The use of these resources led to fewer critical situations than the design brief, but it is expected that they would be utilised in far more Information and Analysis situations during a longer period of work. It is hoped that the full analysis will illustrate this.

4 MOVING TO THE DISTRIBUTED DOMAIN

The design scenarios have helped to develop an understanding of the patterns of team interaction and resource use in a synchronous, co-located environment. Since the research aims to provide a solution for the distributed environment, however, it is necessary to consider issues raised by the associated logistics. The Time-Space matrix, as shown in Figure 6, is a recognised way of categorising modes of communication for the distributed team. The figure shows some of the technologies are typically used by the design team in each mode. Providing a technologically rich environment is crucial to facilitate the multiple modes of communication used by designers, as illustrated by projects such as the iLoft project at Stanford University [16]. Multiple modes of communication such as sketching, conversation and gesture are essential for designers to communicate the subtleties of their designs [17] and as technology improves, the richness of communication helps to communicate many of the more tacit aspects of communication. Rather than focus on the hardware involved in achieving this, however, the research here intends to create a 'mode of interaction' to address the issues with moving a typically synchronous, face-to-face task to a global environment. This involves establishing principles of engagement with the system.

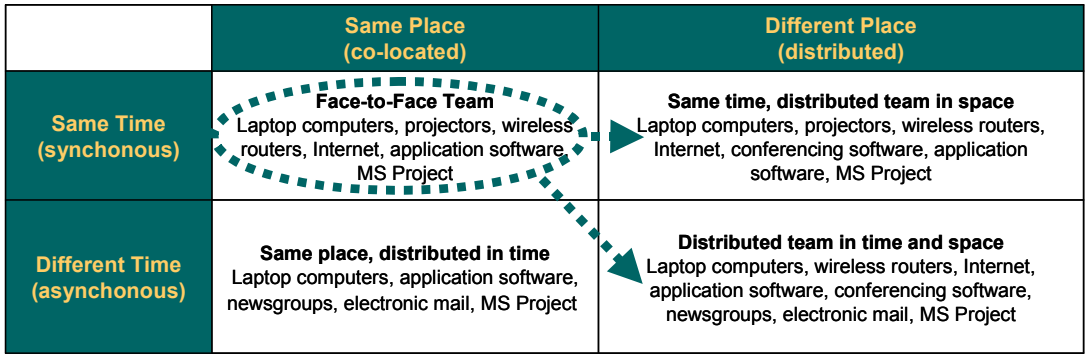

Figure 6. Distributed concept design on the time-space matrix

5 DISCUSSION

Using observations from the concept design scenario and interpretation of the relevant distributed design literature, possible adaptations to the shared virtual design space to suit the design team are discussed.

4.2 Optimising team interactions

As a resource, the project brief was used not only in the critical analysis of the design requirements, it provided the team with a forum in which to reach a shared understanding of the problem. As an initial document to start discussion, it was useful as 'warming up' tool, and could be formalised to incorporate a form of ice-breaker exercise – for example, having everyone discuss their past product experiences relating to specific requirements. Elements such as trust and personality are important to

the success of the free-thinking environment necessary for creative work, and these should be considered in the design of any such environment. This could be in the form of a team forming exercise to position the various team members in terms of personality and expertise. This happened naturally to an extent in the scenario session, and a subtle re-working may be appropriate for the distributed scenario, where gesture, humour and roles are less immediately obvious.

Despite advances in digital communications, there are still limitations in the ability to communicate more subtle and tacit information. The focus of the research is therefore on mechanisms to improve team interaction, rather than the physical environment experienced by the team. It is anticipated that in the development of a model of interaction, the specification of the required hardware and physical environment will follow, and this specification should not rely on 'transparent' technologies. Rather, the model of interaction must be explicit enough to ensure that information is clearly conveyed without making the fluid and dynamic nature of concept generation work seem stilted.

A key requirement for the virtual environment, therefore, is increasing the level of engagement of users to the point where it becomes a useful shared tool. It is necessary to look beyond typical office-based systems which are used to organise and store information to more dynamic and desirable environments: high levels of engagement and co-operation have been achieved in the area of computer gaming, and there are elements of these which may be applicable to a team design scenario. These could consist of co-operative or competitive elements, use of avatars and analogy, exploration of virtual worlds, and other recognised devices used consistently in the industry.

4.3 Optimising use of resources

It has been shown that current digital information systems emerged from the field of librarianship rather than design. Although it was not possible to examine the role of sketching in the short segment of the design meeting analysed, it may be that the analogy of a library is not appropriate for the concept design environment, and something 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 idea. Rather than filing items away as you would do in a traditional library, having them out in the open, in the same environment as the groupware or sharing element of the system, as illustrated in the example of LauLima which attempts to increase this proximity of information searching and sharing tools.

Although the LauLima system has brought information and communication tools closer together, this does not take into account the particular requirements of the concept generation task. If information is made vivid and rapidly available to the design team, they are more likely to interact with these resources. In the scenario session, the fact that models were available to touch, show and discuss sparked team members into discussions on their merits as well as previous experiences. If the benefits of interacting with resources which were not physically present were made explicit, through some form of tagging or tracing, it may lead to a greater willingness to engage with the required digital interface. If, for example, a particular image of a relevant mechanism inspires a concept, the designer could do a sketch and associate it with the stimuli through a tag or similar link. This means that each time the concept is referred to, the corresponding resource is also highlighted. This idea could be extended to recommending resources to other team members, so that items are automatically shown or categorised jointly in a more dynamic sharing and generating scenario. The key requirement is that this process is not inhibitive and indeed aids the 'flow' of concept design work.

The design resources supplied to the team provided a clear jump-off point to design exploration. The team held, discussed and argued over the sketches, models and products before discussing their experiences of using such products and developing ideas of their own. Again, personal experience proved an important factor in the discussion. This could have been augmented by being able to instantly call up the products, environments and technologies they were discussing and referring to. It may be that this is used as a way of diversifying thinking at key points in the concept design task. The PDS or design brief, on the other hand, is traditionally seen as a form of constraint, providing clear limits on design criteria, e.g. maximum product size, product life, functionality etc. Rather than being a limiter to creativity, however, the PDS can be used as a document to help focus creativity on areas

which require the most attention. Using the briefing document as a way to reach a shared understanding of the problem has already been discussed. This could be extended to provide a structure or agenda for the concept design task, ensuring that effort is focussed. This agenda could guide initial resource searches, or ensure that pre-prepared material was available to the team as they addressed each in turn, with certain words activating key information sources, e.g. 'ergonomics' could be linked to certain databases of anthropometrics, images of the body or ergonomically designed products.

5 CONCLUSIONS

This paper has highlighted the importance of accessing and sharing resources during the concept exploration task. The large amount of information handled and the import of the decisions made mean that it is crucial to support design teams in the management and use of resources. The development of current digital library and groupware systems have been highlighted as parallel, rather than integrated environments. It is suggested that by combining elements of these, teams would be able to design in a more information-rich setting. A design scenario was created to understand better the use of resources and interactions of the team, in the form of a simple design task with a brief and limited stimuli. This highlighted patterns of information use in the generating and synthesis of ideas. By incorporating elements from other fields, such as computer gaming and interface design, it is suggested that the current relationship between digital libraries and groupware systems could be enhanced to provide more responsive tools for design teams undertaking concept design work.

REFERENCES

[1] Baxter, M. Product Design: Practical Methods for the Systematic Development of New Products. (Chapman & Hall, 1995).

[2] Wodehouse, A. and Bradley, D. Computer tools in product development. ICED 03, Stockholm, Sweden, 2003, pp. 333-334.

[3] Wang, L., Shen, W., Xie, H., Neelamkavil, J. and Pardasani, A. Collaborative conceptual design- state of the art and future trends. Computer-Aided Design, 2002, 34, 981-996.

[4] Nicol, D.J., Littlejohn, A. and Grierson, H. The importance of structuring information and resources within shared workspaces during collaborative design learning. Open Learning (submitted), 2005.

[5] Bederson, B.B. Interfaces for Staying in the Flow, Accessed 16th March 2003, http://www.cs.umd.edu/hcil/pubs/tech-reports.shtml.

[6] Csikszentmihalyi, M. Finding Flow: The Psychology of Engagement With Everyday Life. (BasicBooks, New York, 1997).

[7] Komerath, N. and Smith, M. Learner Adaptation to Digital Libraries by Engineering Students. American Society for Engineering Education Annual Conference & Exposition, Montreal, 2002.

[8] Broadbent, J.A., Cross, N., Rodgers, P.A., Huxor, A.P. and Caldwell, N.H.M. Design Support Using Distributed Web-Based AI Tools. Research in Engineering Design, 1999, 11, 31-44.

[9] Rubens, W., Emans, B., Leinonen, T., Skarmeta, A.G. and Simons, R.-J. Design of web-based collaborative learning environments. Computers & Education, 2005, 45, 276–294.

[10] Kleiner, S., Anderl, R. and Grab, R. A collaborative design system for product data integration. Journal of Engineering Design, 2003, 14(4), 421-428.

[11] Koohang, A. and Ondracek, J. Users' views about the usability of digital libraries. British Journal of Educational Technology, 2005, 36(3), 407-423.

[12] Mandviwalla, M. and Olfman, L. What do groups need? A proposed set of generic groupware requirements. ACM Transactions on Computer-Human Interaction (TOCHI), 1994, 1(3), 245 - 268.

[13] Grierson, H., Wodehouse, A., Ion, W.J. and Juster, N. Supporting reflection and problem-based learning through the use of LauLima. E&PDE05, Edinburgh, 2005.

[14] Huet, G. Design Transaction Monitoring: Understanding Design Reviews For Extended Knowledge Capture. Mechanical Engineering (University of Bath, 2006).

[15] Badke-Schaub, P., Frankenberger, E. and Dörner, D. Analysing Design Work by Critical Situations: Identifying Factors Influencing Teamwork In Design Practice. International Conference On Engineering Design (ICED 97), Tampere, 1997.

[16] Milne, A. and Winograd, T. The iLoft Project: A Technologically Advanced Collaborative

Design Workspace as a Research Instrument. International Conference on Engineering Design, Stockholm, Sweden, 2003.
[17] Žavbi, R. and Tavčar, J. Preparing undergraduate students for work in virtual product development teams. Computers & Education, 2005, 44(4), 357 - 376.

Contact:

A. J. Wodehouse
University of Strathclyde
DMEM
James Weir Building, 75 Montrose Street
Glasgow, G1 1XJ
United Kingdom
+44 (0)141 548 2628
+44 (0)141 552 7986
andrew.wodehouse@strath.ac.uk