Key Components and Architecture for a Collaborative Product Conceptualization & Bidding System

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Abstract - Singapore manufacturing SMEs are losing ground to operations in low cost countries and need to embrace higher value-add activities such as product development (PD). Simultaneously, increasing globalization and specialization is leading to the formation of design chains for PD. For SMEs to successfully collaborate, bid and perform in such a scenario, they will need the support of flexible tools and processes.

Academic literature, patents, existing software (commercial and free/shareware) and industry processes have been investigated for components suitable for a collaborative product development (CPD) environment. A trial 'collaboratory' has also been set up to gain practical experience.

The outcome of this work is a system architecture for a Collaborative Product Conceptualization & Bidding System (CoProBid). This defines key components which will need to be developed as well as those which can simply be acquired. A number of novel and existing point techniques have also been identified for application in the system.

Keywords: Collaborative product development, Conceptual design, Bid preparation, System architecture

1 BACKGROUND

Product development is now seen as a key mechanism by which companies and organisations can grow by organic means [1], and has become an essential part of many companies' business strategy. Yet in recent years, there has been enormous change in the manufacturing environment [2], including:

- Shorter time to market for new products
- Expanding business globalisation
- Higher levels of technology and innovation expected by the marketplace.

These pressures have led to increased outsourcing and the formation of product development 'design chains', which integrate many organisations with different capabilities. In some industries, this type of collaborative product development (CPD) is now commonplace [3].

Effective business processes and technology are needed to support these design chains [4]. Existing technologies for collaborative product design include standards for the exchange of product model data (e.g. STEP) [5] and the virtual reality modelling language (VRML) for display [6].

Research work on the coordination of design resources includes knowledge based systems to improve communication and help designers search for information (e.g. [7]), as well as tools for organising collaboration activities and rapid prototyping of product concepts [8].

However, most methodologies have emphasized embodiment or detailed design, whereas front end early design has the largest role in defining product innovation, features and costs [9]. Early involvement in product development also provides opportunity for owning IP and subsequent manufacturing.

Furthermore, much research is concerned with the problems faced by large, top tier manufacturers, not small to medium enterprises (SMEs). There are many outstanding research issues for early product development collaboration for SMEs, such as how to manage multi-disciplinary design expertise across organisations, resolve incomplete and imprecise design information, and particularly how to provide low cost, simple systems which SMEs can maintain with minimal IT staff.

2 OBJECTIVE

The business scenario which underlies this research is that of a consortium of SMEs which are bidding to take on the development of a key sub-system within a new product.

In order to provide technology and business support for this scenario, it was therefore important to:

- Investigate business processes and existing technologies for early product design & commercial bidding

- Identify existing methods / technology suitable for SMEs in Singapore
- Use this knowledge to define key components and architecture for a novel business support system.

Hence, this report outlines the initial system definition phase of a wider project.

3 METHODOLOGY

A range of methods and sources were explored to help define an early design and bidding system, including:

- Academic literature search in collaborative early design, commercial evaluation and bidding
- US patent search for key collaborative product development (CPD) technology
- Evaluation of existing commercial and free/shareware software
- A trial CPD environment or 'collaboratory'
- Investigation of industry processes, and studies of local companies
- Discussion & questioning of local SMEs

The possibility of carrying out an industrial survey with local SMEs to define system requirements was initially considered, but this approach was discounted for a number of reasons. Firstly, it is difficult to question potential users about a system which does not yet exist. Secondly, this research is outside the experience of most Singapore companies at the present time (but should be highly relevant in 2 or 3 years time), so responses are unlikely to be meaningful. Finally, proper survey design and administration are difficult and time-consuming. It was thought that direct discussions with 2 or 3 SMEs and process mapping would provide sufficient industry input at the initial stage.

The method for patent searching and analysis was as follows:

1. The US Patent Office database was searched using general keywords, resulting in 2000+ patents.
2. The titles of these patents were used to identify relevant patent classifications in the chosen research area.
3. Within the selected classes, a specific keyword search string was employed to find around 500 patents and applications.
4. Patent titles were again used to filter out obviously irrelevant ones.
5. Details of the remaining patents & applications were investigated.
6. A final list of around 200 patents was submitted to the Aurigin Aureka software for analysis. Its key outputs are a summary of the top assignees, year by year patent volume, identification of cornerstone patents, and the generation of a 'theme map' or 'landscape'.
7. Aureka software parameters & stop words were refined until some meaningful landscapes were produced.

The main method used for software reviews was to scan 3rd party, independent internet based magazines and reviews (Network Computing, Cadence, PDMReport, Federal Computer Week, Internet Week, CNet, Stroud's). These helped to identify the most significant software packages and provided a source of detailed test information. Some of the simpler products were also downloaded and tested in-house.

In addition, for shareware and freeware, top download sites on the web were identified and software was analyzed and compared for popularity / download rate, core functions, sub functions and cost.

There were three aspects to the investigation of industrial processes. Firstly, earlier mapping work carried out by SIMTech of a simple SME design chain in the mould making industry was analysed. Secondly (in partnership with a related benchmarking project at SIMTech), a study was conducted of the product design and development practices of a consumer electronics MNC in Singapore. The inputs of the study were company process documents and regular discussions with one of the company's design managers. Finally, a number of textbook product development case studies were analysed and used as the basis for a full scale process map of a collaboration scenario.

It was decided to use existing commercial software as the basis for an experimental collaboration environment, or 'collaboratory', for the two organisations involved in the project. The main objectives were to:

- Test and uncover the detailed features, strengths and weaknesses of selected software
- Identify potential feature gaps for research work
- Trial collaboration methods & processes
- Gain hands-on experience of product development
- Promote a practical focus within the research team, for an abstract area of research.

This was achieved by installing and configuring a server in SIMTech, which was opened up for access from MPE. An experimental collaborative product development project was then initiated and issues / experiences were recorded during use.

4 RESULTS AND DISCUSSION

4.1 Literature review

From the review of academic literature, collaborative design tools can be broadly categorised into two areas, namely collaborative design infrastructure and intelligent tools for design.

Collaborative design infrastructure includes tracking and monitoring decisions, managing data sharing, utilising external information sources and virtual reality enhanced design.

For tracking and monitoring decisions, limited functionality is provided by CAD systems where archive files are maintained. [10] proposed a collaborative design system for product design that resolved conflicts by a series of check-in, check-out and direct operations. Such a mechanism allowed a user to create or edit a drawing while other users participated passively or actively.

Managing data can be achieved by off-the-shelf databases. External information sources are important because 40% of communication during the design process is with external participants [11]. These can be accessed via the Internet e.g. [12], who extended an open hypermedia system to accommodate collaborative design. Nevertheless, it seems that methods of managing this information have not been properly addressed.

Virtual reality enhanced design allows designers to communicate interactively with others. [13] presented the application of CAVE (Cave Automatic Virtual Environment) and Powerwall virtual reality systems to collaborative design. The study revealed that virtual reality was indeed able to improve communication and identify design problems. However, their application was mainly to gather feedback, where minimal decision-making assistance was rendered.

Intelligent tools for design are able to assist designers in specific tasks such as the generation of textile patterns, predicting the overall impact of design changes and creation of alternative concepts. Attempts have also been made to develop systems which anticipate problems, alert designers and provide solution advice e.g. [14].

Artificial intelligence approaches such as expert systems, case based reasoning, artificial neural networks and fuzzy set theory have all been employed. For example, [15] presented an expert system to assist designers in designing power converters. An optimum topology was generated based on the given specifications. However, all the existing methods have problems. For example, expert systems have difficulties in maintaining and updating the knowledge base, while neural networks are difficult to interpret directly and evaluate solutions.

Traditional bid preparation comprises an established process in which the project information is passed on from one department to another – usually in the form of a growing set of paper work [16]. A collaborative bidding process differs from a traditional one, but still contains the same three phases: pre-bidding, bidding-design and post-bidding.

In the pre-bidding phase, potential contracting companies evaluate and assess the bid against their current conditions [17], to decide whether to bid or not. The preliminary assessment checks a small number of readily discernible features of the tender which may preclude submitting a bid. For example:

- Contract size: too big or too small
- Conditions of the contract: non-standard or against company policy
- Location of contract work: too distant or too difficult.

The bidding-design phase is the most important part of bid preparation since it contains product design and development, cost estimation, and production scheduling. In the post-bidding phase, the bid is awarded to the company and often adjusted through a negotiation process between supplier and customer.

Cost estimation during bidding-design is a key element of the final market price (along with the price of comparable products) and can determine product success or failure. Considerable work has been undertaken in the area of costing, particularly for manufacturing and machining e.g. [18-19] and lifecycle costs [20].

Function costing techniques were proposed by [21], which estimate relative costs of an individual component from a specification of its function. However, such techniques are complicated where the function of a component is not clearly defined, multiple functions are to be considered, or where a complete system is considered.

More recent work describes activity based costing (ABC). This approach assigns the cost of resources to the activities necessary to produce a particular component, including all aspects of production and services such as administration and distribution [22]. While these may be accurate accounting tools, they are not particularly useful during the early stages of product design, when designers wish to compare various configurations and component types.

There is some work on product cost estimation using neural networks. [23] applied back-propagation neural networks to estimate the cost of assembly systems. Emphasis was on the comparison of performance between the neural network model and the regression model. With the historical cost data, the neural network is capable of learning cost estimation knowledge and performing function approximation. However, determining the number of hidden layers and the number of neurons in each hidden layer can be a time consuming trial-and-error process since there are few guidelines. Other limitations are that neural network training requires experience and accurate historical data must be available.

The available cost estimation methods can solve problems in some fields, but there is still no comprehensive method for use during the bidding process in a collaborative environment. Therefore one aim of this project is to develop a costing method that can support designers distributed in different companies to determine the cost of a new product.

A product development process contains inherent iteration which extends its lead-time and cost. Managing these iterations is of great importance for efficient product creation, particularly in a collaborative environment.

Several models or approaches have been developed to analyse sequential, parallel and mixed iteration. The Work Transformation Matrix (WTM) model was developed to analyse purely parallel iteration and identify the convergent rate of the iteration, which is dependent on the eigenvalues of the work transformation matrix [24].

To tackle purely sequential iteration, a Predictive Sequential Iteration (PSI) model has been proposed to estimate the expected duration of a coupled design process by constructing a Markov chain for the process [25].

For analysing real world mixed iteration, a variety of approaches or models have been suggested by different researchers. [26] presented a simple and structured model to coordinate two coupled development activities through frequent reviews. The frequency of progress reviews is adjusted to minimise project completion time and also improve quality. However, these models are only effective in dealing with the iteration of two activities and are fairly difficult to employ for the analysis of multiple tasks.

For mixed iteration with multiple tasks, only the model introduced by [27] is able to estimate the probability of completing a product development project over time. Nonetheless, it is only effective for small size development projects that contain a fairly limited number of activities. The computation and complexity expands dramatically with increasing numbers of activities.

The early product design and bidding process can also be treated as a knowledge / requirements handling process, containing knowledge acquisition, representation and organization.
Methodologies for knowledge acquisition include non-contrived or informal techniques (e.g. survey/questionnaire, self report) [28] and contrived or formal techniques (e.g. sorting, repertory grids.) [29]. However, engineering design knowledge acquisition techniques are still poorly developed (especially for conceptual design) because (1) few researchers have thoroughly examined this issue; and (2) design knowledge elicitation in the early stage of product conceptualization has different characteristics from that in later stages of the product life cycle e.g. a large quantity of incomplete/imprecise information.

Generally, there are three basic structures for knowledge representation – matrix, hierarchy and network. Compared with a network architecture, the hierarchical structure is easy for novice elicitors to use (e.g. simple structure, fast recording, controllable process), effectively represents multi-disciplinary knowledge (e.g. broad knowledge coverage and clear-cut symbolic, semantic, diagrammatic, cognitive, mathematical and psychological abstraction levels), and easy for quantitative analysis (e.g. programming/automation using O-O and NN technology) [30].

Design knowledge reasoning and design decision-making take place at every stage of a design process for the selection of technical options. In recent years, it appears that the application of AI techniques prevails in design decision-making. Near optimal solutions can be generated by employing such frequently-used techniques as the genetic algorithm (GA), fuzzy inference system (FIS) or neural network (NN) [31]. However, these approaches are inappropriate to this project since Singapore SMEs generally have small data sets.

4.2 Patent search

The patent search confirmed that there is an increasing pace of invention in Collaborative Product Development, suggesting it is a fertile field for research with significant potential for generating intellectual property. IBM appears to be the most active organisation in the field.
The significant patent clusters were:

- Multimedia conferencing i.e. real-time virtual meetings employing audio, video, text chat, applications, mark-up, sketching tools etc.
- Creating and using a collaboration space i.e. communicating via a virtual project area where documents can be shared, meetings can take place, progress can be monitored etc.
- Data libraries for collaborative design i.e. logical organisation of design information for multiple users and for knowledge capture.
- Collaborative web browsing & feedback i.e. demonstrating web pages to others and gathering data from the web.
- Sharing databases i.e. allowing a database in one location to be accessed by databases and programs in other locations.

4.3 Software review

The software review focused primarily on inter-organisational (i.e. web based) collaboration and the requirements of SMEs i.e. less than 50 seat, low cost solutions.
The following main software groupings were first identified:

- Web Meeting tools for on-line, real-time meetings between members of a collaborative effort (includes instant messaging (IM) and multimedia conferencing software).
- Virtual Team, Project or Workspace tools for organising and streamlining a collaborative, distributed team or project.
- Content or Knowledge Network tools for helping members of a collaboration effort to access, collate and understand distributed information (includes search engines and document management software).
- Portals which provide employees with a single access point to key enterprise content and applications (related to thin client software).
- Product Data Management (PDM) or Product Lifecycle Management (PLM) software for managing the complex web of information surrounding new product development.
- CAD Web Sharing software which provides internet access to data-intensive CAD files (related to 3D visualisation and virtual reality software).

The combination of third party reviews on the internet and internal testing indicated the most significant software tools for internet based collaboration by SMEs as shown in Fig. 1.

An interesting additional factor is the use of CAD systems in Singapore. In fact from discussion with experienced designers, it seems that AutoCAD, SolidWorks, and Unigraphics are the most widely used systems. However, the adoption of expensive systems such as Unigraphics and ProEngineer has been skewed by past government upgrading initiatives. 2D users and green field sites are now taking up the mid-range CAD systems, particularly SolidWorks and SolidEdge. SolidEdge has the further advantage that software seats are freely available at NTU.

4.4 Industrial processes

From the investigation of a Singapore based SME and MNC, it was found that these companies work together with their sub-contractors and partners in a product design cluster (see Fig. 2). This supports the academic observation that competition often takes place between design and supply chains, rather than individual organisations, in order to achieve shorter time-to-market and lower costs.

From the MNC process study, it is thought that SMEs could play a role in supporting MNCs in the product design chain. Yet to gain competitive advantage, it will be necessary to define an appropriate industrial positioning, and identify supporting approaches and technology tools. This confirms the initial project rationale for developing CPD tools for SMEs.

The academic case studies and process mapping of a collaborative scenario showed that the majority of the product development activities (R&D, conceptual design, make or buy investigation etc.) are iterative in nature. By contrast, parallel activities in other organisational functions tend to be more singular in nature, with perhaps occasional re-visits driven by product changes. Product development also plays a key role in coordinating the activities of other functions.

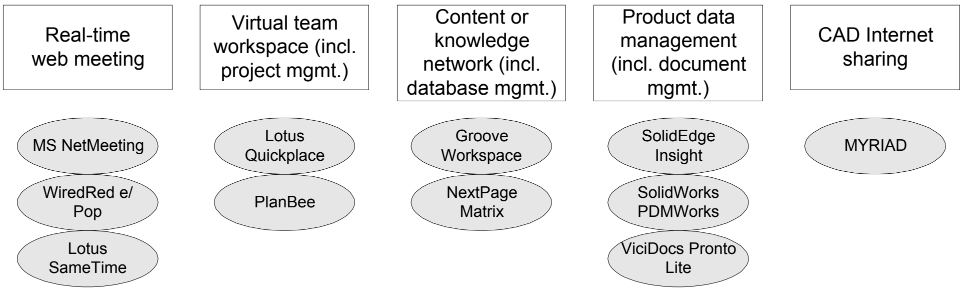

Fig. 1. Most promising existing software.

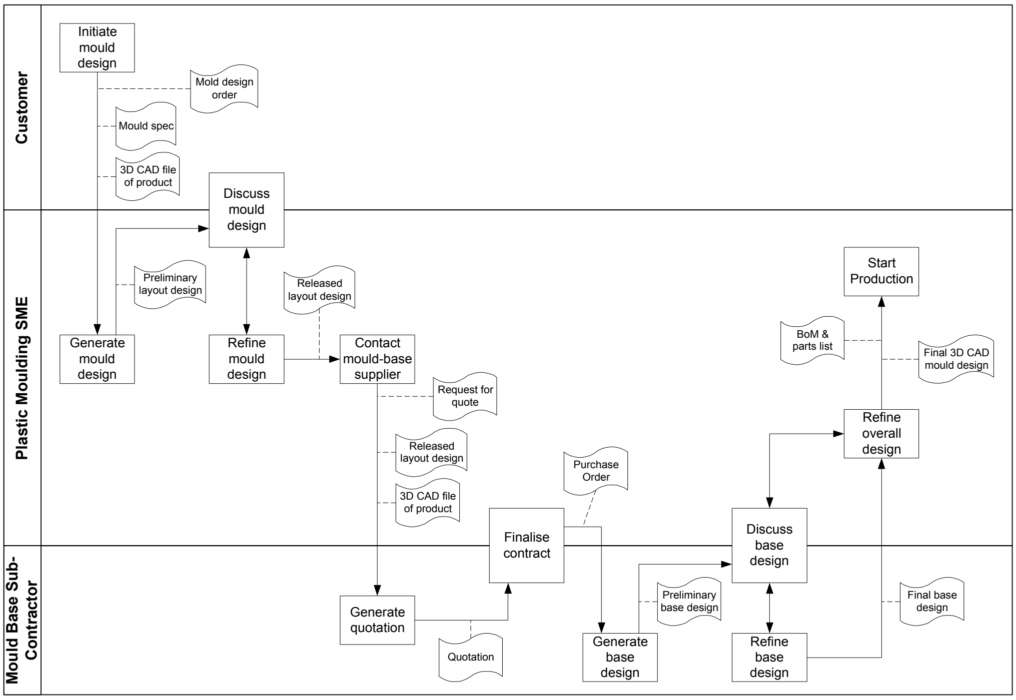

Fig. 2. Design chain for a plastic moulding SME.

4.5 Collaboratory

It was decided to use Lotus Quickplace as the basis for the trial product development environment or 'collaboratory' (S$60/user), and Microsoft NetMeeting (free) for real-time communications.

Installation of Lotus Quickplace on a Windows 2000 server was relatively straightforward, first installing the Lotus Domino database, then Quickplace on top. Connecting the server within the SIMTech network was more difficult: the network administrator was required to open port 8080 for incoming and outgoing messages and registered the server on the SIMTech DNS. Microsoft's Internet Information Server (IIS) had to be removed from the machine, and finally a package called Domino Server Admin was needed to point the database to the correct SMTP client URL to enable Quickplace emails.

A number of potential partners and products were explored before choosing the subject of the product development test environment – a novel human powered water craft. The overall design scenario is that SIMTech Watercraft are a lead OEM, and are to engage a collaborative design partner for the development of the drive train and propulsion system. One of the potential partners is MPE Propulsion.

This research is ongoing, but activities to date include:

- Initial concept design (SIMTech) i.e. Product concept generation, Concept evaluation/selection

- Commercial Evaluation i.e. Market Analysis, Financial/resource planning (SIMTech)
- Tender for sub-system design i.e. Tender preparation (SIMTech)

Some problems with Quickplace and NetMeeting identified so far:

- Quickplace uses a 'Page' metaphor for all entries, since it is web-based, and this can be unhelpful e.g. when uploading a file to a folder.
- The 'Task' and 'Calendar' tools are practically unusable since every change requires a browser refresh. The workaround has been to post schedules as Gif image files.
- An explicit method of monitoring and reporting project progress would be useful, so that all team members are aware of parallel / dependent activities.
- NetMeeting only allows two participants simultaneously for voice / video. As a result, an on-line meeting was attempted using mainly the text chat facility. This was broadly successful, but found to be difficult to initiate, poor typists were at a disadvantage and typing delays meant that there were often several conversation threads running in parallel. The use of text meant that recording of the meeting was comprehensive, but the transcript was too long to properly replace minutes.

5 CONCLUSIONS

From the analysis of literature, patents, existing software, industrial processes and some practical experience, the system architecture shown in Fig. 3 has been defined. The bottom layer shows server side applications and databases. These components already exist and can simply be acquired. The next layer shows elements which will need to be provided in the user interface. Although this project focuses on early collaboration, it will still be necessary to provide links to existing intranet based CAD systems for later detailed design.

The 'Product knowledge / requirements management' layer (acquisition, representation & organisation) is of great importance, because it pulls together all the components into a seamless product development and commercial management system. This includes, but is larger in scope than, Product Data Management and the sharing of internet data sources. It is expected that commercial software such as Solid Edge Insight will need to be augmented with academic techniques.

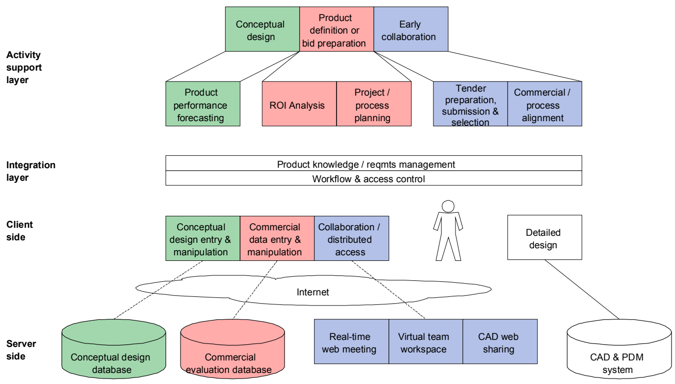

Fig. 3. System architecture for a Collaborative Product Conceptualization & Bidding System (CoProBid).

Finally, the activity support layer will provide some important point solutions for conceptual design, bid preparation and early collaboration, employing a number of existing and novel techniques.

6 INDUSTRIAL SIGNIFICANCE

Singapore based SMEs and MNCs are now much more susceptible to the changing global business environment. For example, the increasing manufacturing capability of low cost regions is absorbing investment that in the past would have been channelled towards Singapore [32]. In addition, by its nature and size, Singapore has a limited critical mass of organisations within its shores that represent the complete value chain for a particular product or service.

Hence, Singapore manufacturing is now aiming to diversify by moving up the value chain into product development [33]. Although contract design represents an extension to the contract manufacturing role, large global MNCs are seeking to outsource more product development activities with high expectations of quality levels, understanding of the market requirements and innovation [2].

To achieve and support this emerging role for Singapore based companies, especially SME's, business processes and technology solutions for collaborative product development are needed. In particular, to identify and satisfy market needs, front end design forms a key component of business decision analysis and subsequent customer solutions. It is thought that collaboration in early product development phases will enable design chains to be formed which can bid and participate in global product development projects.

Some of the key components and architecture for a collaborative early design & bidding system are addressed by this project. It is planned that such elements will be taken up by pilot industry groups to aid their transition. One possible mechanism for the use of such a system would be adoption by an industry focused consortium that identifies common goals and objectives. This would provide an environment for validation and potential future commercialisation.

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