Int J Adv Manuf Technol (2008) 35:1028–1040
DOI 10.1007/s00170-006-0788-8

ORIGINAL ARTICLE

A Web-based integrated design system: its applications on conceptual design stage

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Received: 18 October 2005 / Accepted: 4 September 2006 / Published online: 22 November 2006

Abstract This paper describes the development of a Web-based integrated system for collaborative product development evolving from marketing analysis to prototype generation. The proposed system encompasses a marketing information system (MIS), a human resources management (HRM) system, a supply-chain management (SCM) system, a communication media, an integrated product design studio, a user interface and databases. It enables project planners, marketing analysts, designers, suppliers, and manufacturing planners to work at the early stages to reduce any unnecessary wasted time, resources, and costs, thus increasing the total product quality, maximising the organisation resources used, and reducing the total product cost and product lead time to better face global competition. The tangible advantage of implementing this system is that it provides an integrated environment for total product development from concept to realisation. Therefore, an efficient product development process is generated. One case study is demonstrated and discussed to validate the proposed system.

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Keywords Collaborative product development · Computer-aided design · Concurrent engineering · Data sharing

1 Introduction

Global product development is a contemporary inclination supported by advanced technologies and global marketing. Utilising the technologies available today, short-term project-based collaboration is quickly becoming recognised as a competitive necessity. Organisations involved in the design and development of new products have to adopt flexible, dispersed methods of working in order to meet the numerous and varied demands of the global marketplace. Connected through the information and communication technology, a manufacturing organisation will design a new product in direct collaboration over product development networks, involving multi-disciplinary marketing, design, and manufacturing teams.

Recent research work has been carried out in the area of developing an integrated product-design approach [1–4]. Goldman et al. [5] declared that with the emergence of information technology and the convergence of computer networking and telecommunication technologies, it is no longer a requirement for people or cooperative organisations to be located in the same place in order to communicate. Hence, some research works have investigated the difference between typical design collaboration and distributed design collaboration [6, 7]. Moreover, research work into the collection of marketing information and its analysis were discussed by Wee [8], Buttery et al. [9] and Trappey et al. [10] and human resources management were discussed by Saa-Perez and Garcia-Falcon [11].

To develop such an integrated system for design collaboration, it is clear that there is a need for a new approach that considers the holistic point of view for product-development activities. Firstly, an architecture for global collaborative product development should be built. Secondly, the proposed integrated system should accomplish an environment that considers the differences in the multi-users' background, experience and expertise in order to develop the user-centred interfaces for distributed collaboration. Thirdly, the system should integrate the most frequently used tools and techniques for product design and development processes. Finally, the system should advise users on how to eliminate design- and manufacturing-related conflicts that may arise during the product development cycle.

This paper presents a Web-based integrated design system for collaborative product development designed to facilitate the collaboration of product development involving four essential stages: administration, marketing, design and manufacturing. Section 2 describes the overall structure of the proposed system. Sections 3 and 4 present both the architecture and the functionality of the system through a case study. Finally, discussion is presented in Section 5.

2 Overall structure of the proposed system

The proposed system is a prototype system that supports the needs for collaborating and sharing information and tasks, with involvement from marketing analysis to concept development, over the Internet. It aids product development by providing a platform for early collaboration between team members in distributed locations.

The proposed system encompasses a marketing information system (MIS), a human resources management (HRM) system, a supply-chain management (SCM) system, communication media (CM), an integrated product design studio, and user-centred interfaces and databases as shown in Fig. 1. An overview of the proposed system, including a working scenario, is briefly described in Section 3. The overall structure of the proposed system is shown in Fig. 1. A case study is demonstrated and validated in the proposed system in Section 4.

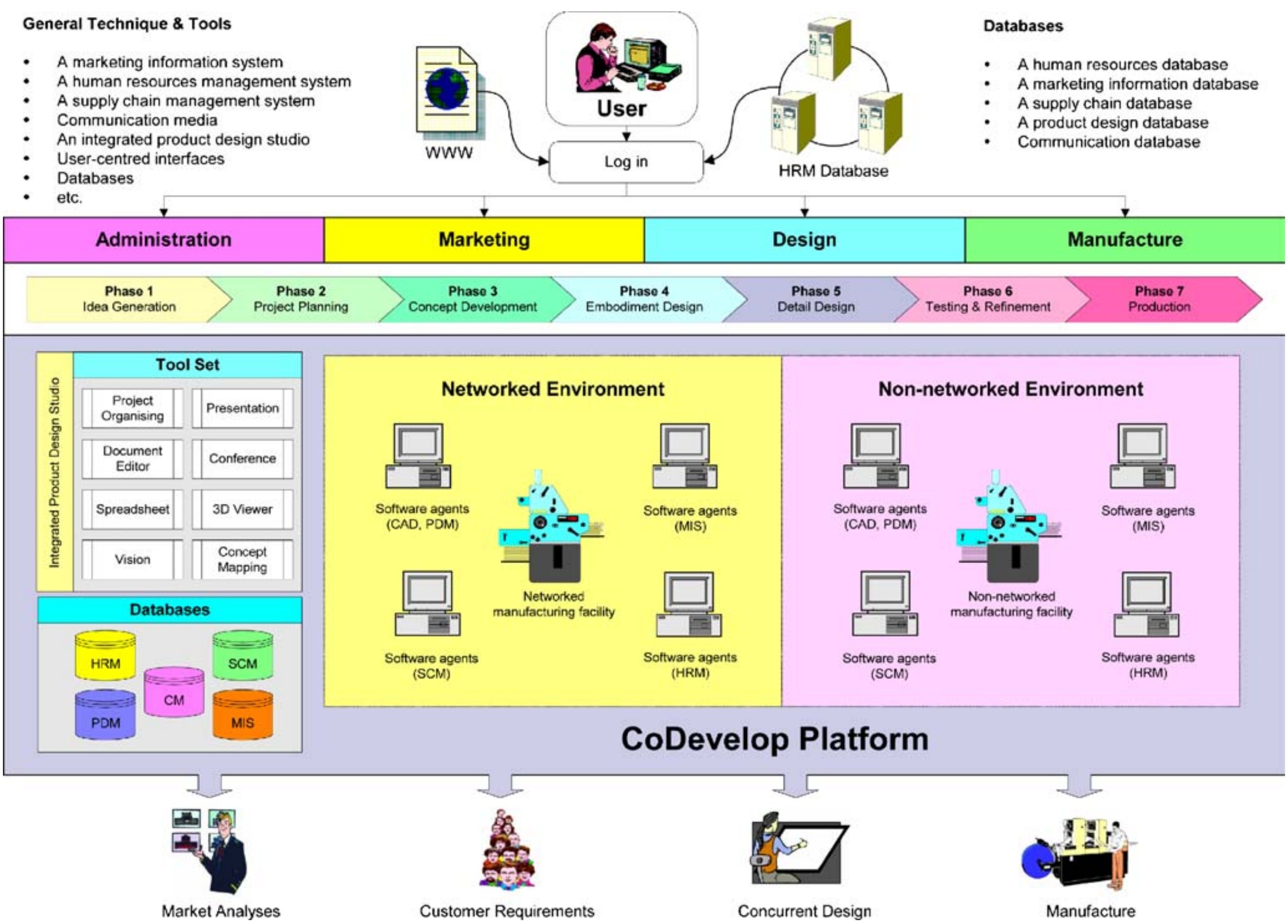

Fig. 1 The overall structure of the proposed system

Supported applications are described in more detail as follows:

A marketing information system A MIS system involves the capability of the decision-making, which is often a very complex process, consisting of people, equipment, and procedures to gather, sort, analyse, evaluate and distribute needed, timely, and accurate information to better assist marketing researchers. The information needed by marketing researchers can be obtained from several conducts: internal organisation data, marketing intelligence and marketing research. The decision support for the marketing information system focuses on sales analysis, competitor product analysis and strategic planning.

Human resources management system A HRM system fundamentally consists of a range of tasks designed to ensure that the appropriate number of the appropriate personnel are in the right place at the right time. In essence, it involves assessing current levels and utilisation of staff and skills, relating the internal elements to the market demand for the organisation's products and providing alternatives to match human resources with anticipated demand. The proposed system is available to highlight and suggest the suitable person to join a new product development team, based on a matrix model [12].

A supply-chain management system During collaborative product development, suppliers may have to design and manage their components with a view to their total life cycle environmental impact. The life-cycle perspective comes in with the requirement that the suppliers should apply the producer's requirements to their own suppliers. Hence, a proposed system involves a materials database, product data information, and extensible rules to comply current local and international environmental regulations, which has been complied from information delivered by their suppliers.

A communication media Communication media (Fig. 2) provide six integrated functions to support both asynchronous and synchronous distributed interactions among team participants. The functions of both E-mail and bulletin-board support the asynchronous interaction. The others are

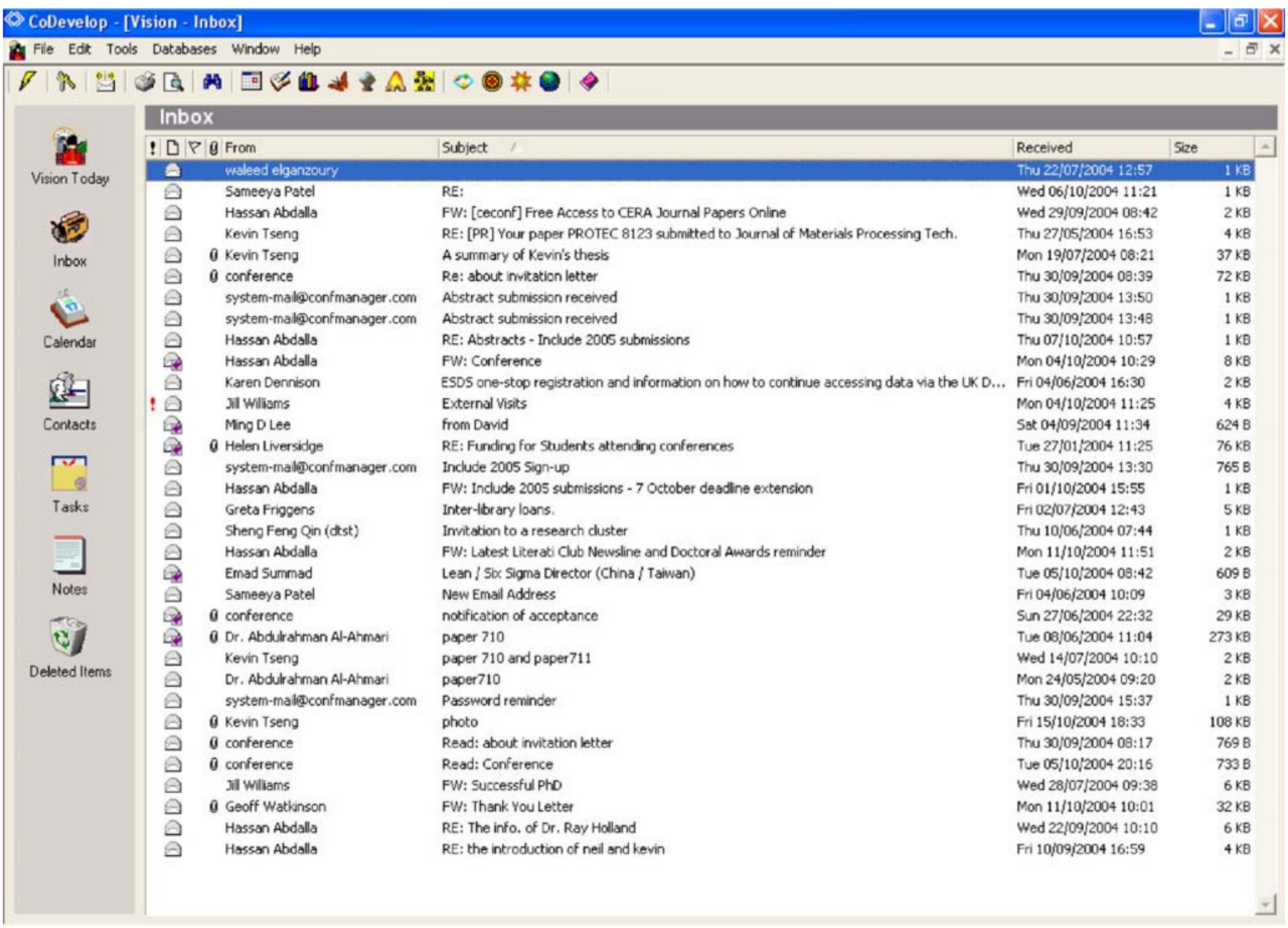

Fig. 2 A snapshot of communication media

online list, instant message, online conference room and 3D viewer, which allow the synchronous interaction in real-time.

Concept mapping module A concept-mapping module (Fig. 3) is a tool to help team members to restructure their own ideas in the systematic way displayed. It is the representation of a group of related and interconnected concepts and their relationships to each other. Idea screening evaluation forms the gathering of loose ideas from team brainstorming sessions. Likelihood analysis provides help to evaluate the ideas. The results are revealed in presentation mode and are able to be discussed in distributed locations. A concept-mapping module utilises this natural cognitive mapping mechanism that people normally use. Conceptual mapping can be likened to Mind Mapping™. However, it extends this useful information exchange or structuring mechanisms in various manners.

An integrated product design studio An integrated product-design studio encompasses a CAD module, a self-developed product data management (PDM) module, a database module, human-centred user interfaces and the design studio tool set that is incorporated with product process planning software to facilitate process planning and management. The CAD module incorporated with a commercial CAD software depended on the application of its organisation. In this case, AutoCAD selected incorporates with the developed system for team members collaborating and sharing a design prototype during product development. The PDM module centralises the data in an easily accessible environment allowing users to store, access and modify information in a fast and controlled manner. It enables project planners, marketing analysts, designers, suppliers, and manufacturing planners to work at early stages to reduce any unnecessary wasted time, resources, and costs, thus increasing the total product quality, maximising the organisation resources used, and reducing the total product cost and lead-time.

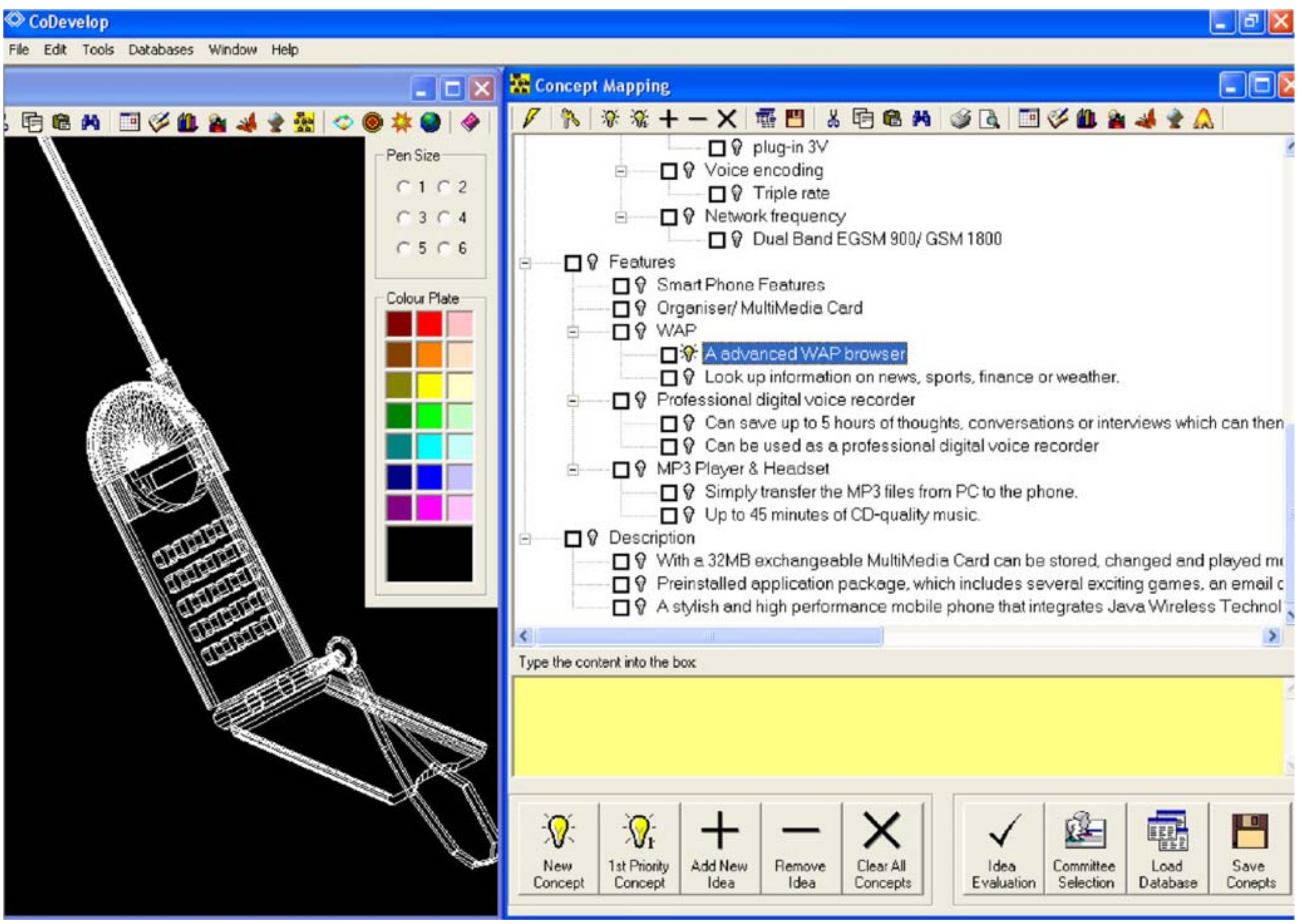

Fig. 3 A snapshot of the concept-mapping module

2.1 Databases

The proposed Web-based integrated design system was developed using both relational and object-oriented database approaches. It is categorised into five separate groups of database: a human resource database, a marketing information database, a supply-chain database, product design database, and a communication database.

These databases are used as centralised databases for storing information pertinent to the human resource data, the marketing information data, the product design data, the supply-chain data and communication data. In this research work, both the relational database and object-oriented database have been implemented. The human resource is stored alone on three levels, namely, employee information, project description and project performance levels of the component in the form of database tables. At the employee information level, employee background information such as name, title, photo and other employee information are stored while various project descriptions such as aims, objectives, assumptions, labour hours, etc., are stored at the project description level of the database tables. The project performance-level database contains information such as task record, project ID and employee ID. The attributes of the employee information, project description and project performance-level database tables consist of both assigned values (text, numerical values, etc.) and OLE (Object Linking & Embedding) objects. The above attributes can be interactively specified by the user in order to specify employee speciality or could be retrieved as a response to a query on a specific project performance. The three database tables are related to each other through database entity relationships. The queries were created using SQL (Structured Query Language). The SQL sequence is translated by the MS-Access ODBC (Open Database Connectivity) driver before it is sent to the MS-Access database server for retrieving the appropriate database records. The service for providing access to the data in the database is managed by Microsoft's Internet Information Server (IIS), which continuously monitors for service requests from client interfaces. The client interfaces consist of pre-designed forms created by both client-side language such as HTML (Hyper Text Markup Language), JavaScript and VBScript and server-

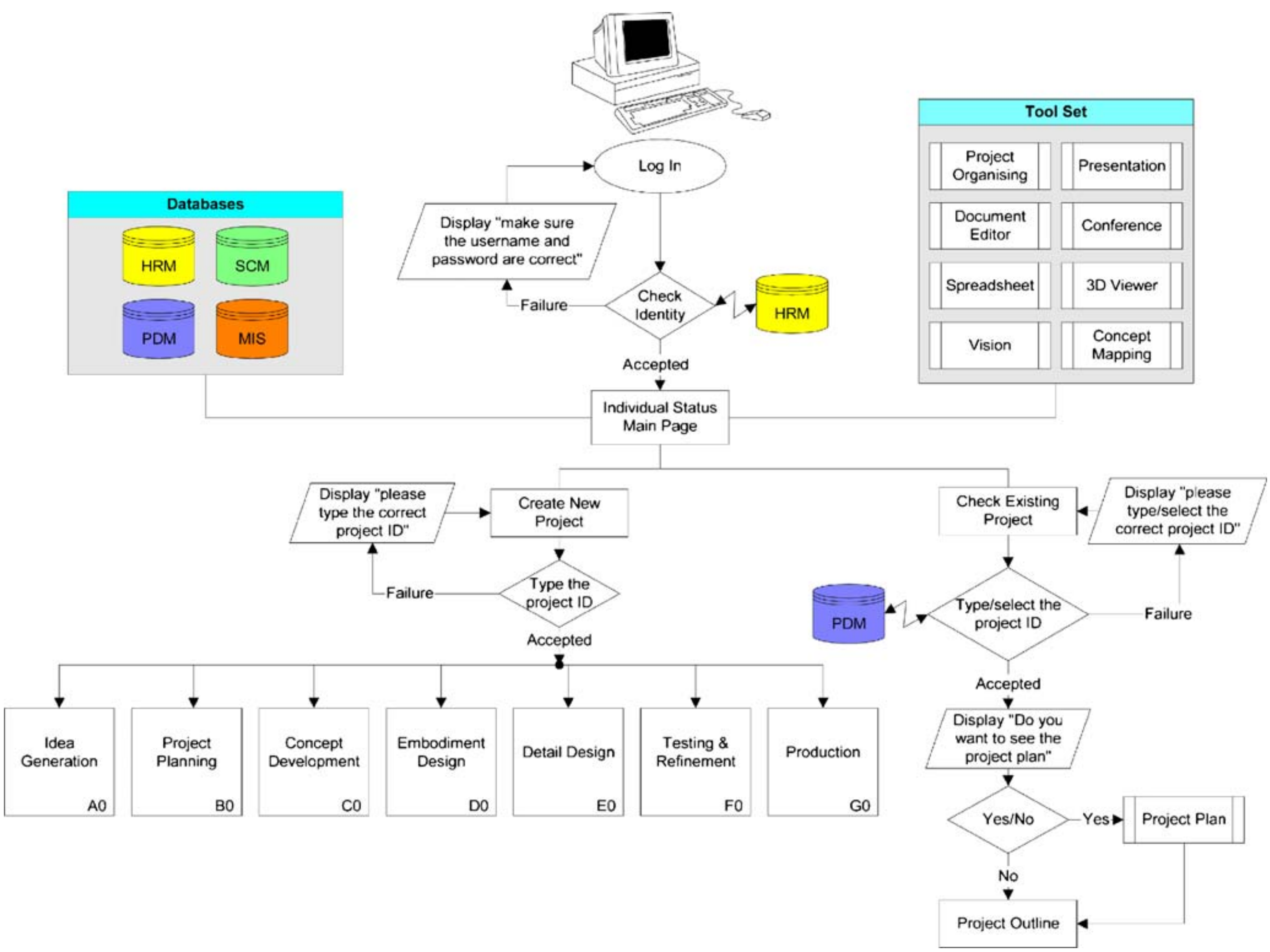

Fig. 4 System scenario

side language such as PHP (PHP: Hypertext Preprocessor) for entering or retrieving data from the database.

The marketing information is stored in two levels, namely, area and product information of the component in the form of database tables and is associated with the POS databases. At the product level, product information such as cost, product name, abstract and description are stored. The attributes of the area and product information-level database tables consist of assigned values and hyperlinks to the HTML format compliant documents such as graphic images (including analysis diagrams) and text files. The supply-chain information is stored in six levels, namely, category, clients, order detail, orders, products, and suppliers of the component in the form of database tables. At the clients' level, client information such as name, address, organisation, and notes are stored while order details such as order name, product number, and case are stored in the order details level. The product, order, and suppliers' information such as order number, order date, quantity, supplier name, supplier phone, etc., are stored separately in product, order, and suppliers levels. Similar techniques such as SQL, ODBC, PHP, HTML and IIS are used to connect user interfaces and databases for entering or retrieving data from the databases.

Due to the complexity of the product design and communication data, plus the additional linking framework, the choice was made to use an object-oriented database for both product design and communication information. Complex data can be modelled in a relational database; however, this is difficult to do. Data often needs to be deconstructed upon entry into the database and reassembled on retrieval. When there are lots of relationships between the data, the multiple joins required in reconstructing it become severely degrading to the system's performance.

An argument around this for a relational database supporter is that the data could be de-normalised reducing the number of joins needed. However, this results in repeated data that in turn is an inherently inefficient use of resources, and furthermore allows the possibility for the data to become inconsistent during updates, a strong possibility in a concurrent access system.

Within an object-oriented database many-to-many relationships can be expressed directly instead of having to join the data as is the case with a relational system, the data can be traversed as a graph data structure. The successive index searches and joins which the database would have to undertake to traverse the graphs generally means that it would be slower than the object-oriented database for this type of data.

The new object-oriented approach in database design has claimed its advantages on reuse, faster development, semantic enrichment, more flexible representation of data and less impact in terms of changing requirements [13]. Therefore, object-oriented databases are ideally suited to the storing of complex product design and communication data. A concept database and a product database are used within this research. The concept database stores the concept map XML (extensible markup language) data structures and the product database stores the STEP (standard for the exchange of product model data) product data. Each database is connected through links embedded within the concepts.

3 System scenario/implementation of the proposed system

In modern manufacturing organisations, many systems have been built to support the collaborative product development process. These systems can be generally grouped into the following categories:

– Product information management and exchange systems for designers to timely obtain the necessary product data and knowledge [4, 14, 15];
– Web-based collaborative product design systems [16–18];

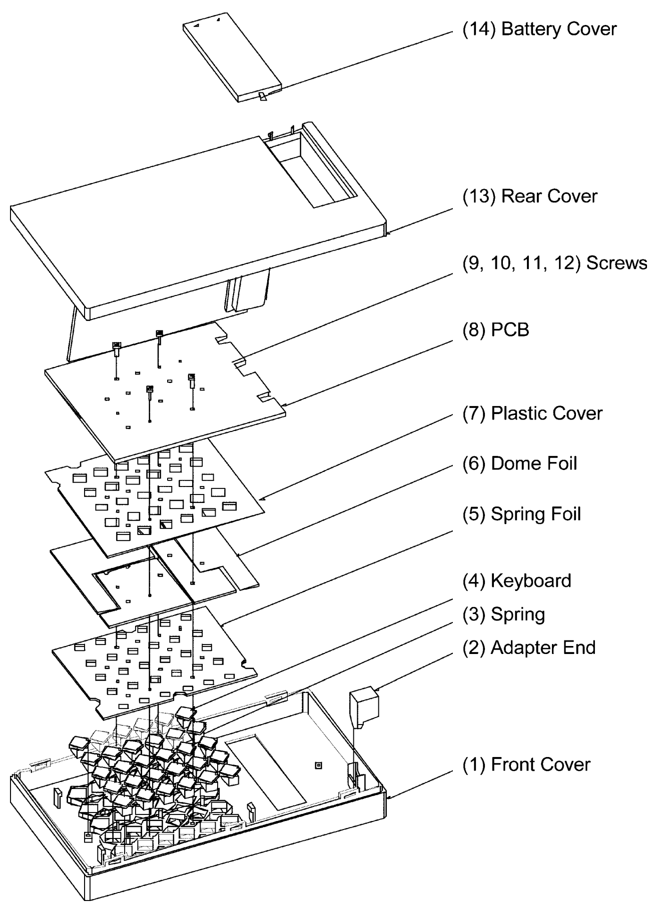

Fig. 5 Exploded solid modelling diagram of a scientific calculator

– Collaborative product development process management systems [19, 20];
– Conflict detection, management and resolution systems for collaborative design [21].

The above software systems can assist design team members in one way or another in collaboration, since most of them are developed for the needs of collaborative product development. A software tool that can provide efficient coordination and decision-making mechanisms for design team members is needed, because of the following necessities:

– During the product development process, design team members often have limited knowledge and information to accomplish product design tasks. For instance, the marketing analyst in the design team has not a sufficient concept of which materials and tools are used and how much they cost for product manufacturing. Therefore, letting the right specialists offer the necessary design suggestions at the right time is essential;
– In the product design process, most design problems can be solved with different strategies, and these strategies may have different impacts on the design cycle, quality and cost of products, so the resolution of single design task is the foundation of the whole resolution plan. Therefore, it is an intelligent requirement for product design tools, suggestions, and processes to facilitate design team members to find a most satisfactory resolution strategy for every design task;
– During the complexities of product development, many software agents have been applied to help design team members either analysing market trends or solving technical problems in the product design process. The reasoning module of the agent—a set of member functions of the agent classes, cannot be adaptable enough to satisfy theses design requirements. Therefore, it should be a feasible method to incorporate the working mechanism of expert systems into the agent to improve its intelligence and adaptability.

A Web-based integrated design system for collaborative product development is developed to solve the problems mentioned above. In the implementation of the developed system, the design team members can use the developed system, either running the entire integrated system for

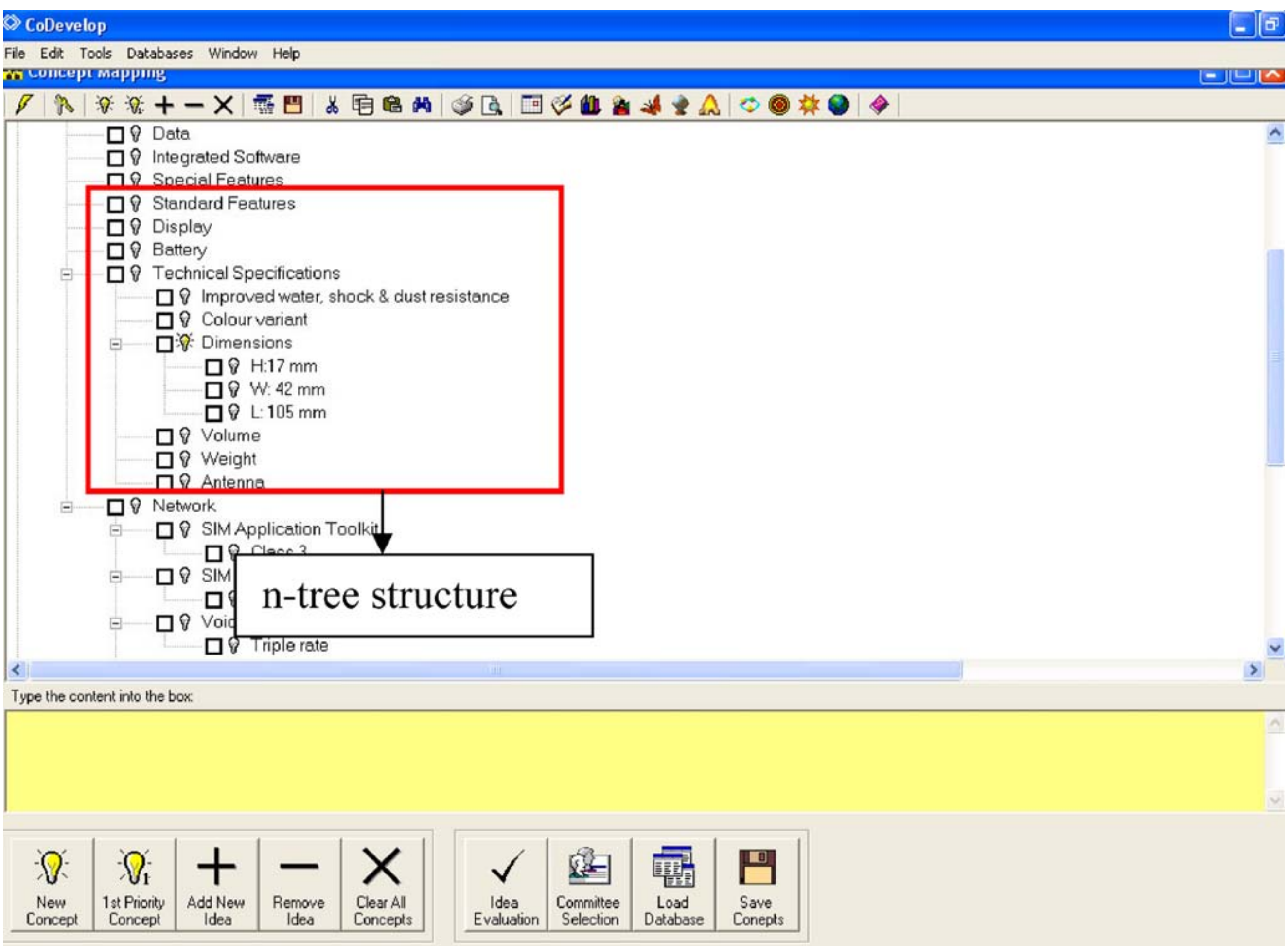

Fig. 6 Concept mapping interface

Table 1 The data of information

Information	Data
Product name	Scientific Calculator
Annual production volume	250,000
Number of production shifts	3
Design style	5
Number of components	14
Number of different components	2
Product market life	4 years
Part defective	0.8%
Annual cost per operator	£14,625
Capital expenditure allowances	£25,000

online collaboration with other team members, or operating a sub-system for executing individual tasks separately. The system runs in real-time. It facilitates and supports the product development throughout the life cycle. Several tools, which are project organising, presentation, document editor, conference, spreadsheet, vision, 3D viewer, and concept mapping, are available for team member use to complete tasks. The tangible benefit of implementing this system is that it provides an integrated environment for holistic product design from concept to realisation. Therefore, an efficient product-development process is generated and identified. The team participant can effectively implement this system collaboratively to perform a project at distributed locations. The main function of this system, besides allowing the team participants to work at distributed location, is to recommend appropriate marketing strategies, to help project planning and the selection of team members, and to provide advanced tools for collaborative design. In addition, the customised template provided is offered so that the less-experienced user is able to manage the holistic product design process. These recommendations are based on marketing information, human resources, manufacturing resources and capabilities that the user provides to the system. It enables project planners, marketing analysts, designers, suppliers, and manufacturing planners to communicate in the early stages to reduce any unnecessary wasted time, resources, and costs, thus increasing the total product quality, maximising the organisation resources used, and reducing the total product cost and product lead-time in order to face global competition. The procedure for the implementation of this system is illustrated in Fig. 4 and the evaluation procedures for the developed system are outlined in the next section.

4 Validation of the developed system

The developed system enables domain specialists to share information, manage products produced during the design process from the initial phases of the product development life cycle, and provide continuous support for development throughout the subsequent phases. The key to this is providing a representation framework that is adaptable to the increasing levels of details and the amount of products produced during the design process.

The developed system was evaluated using products from the electronic sector for simulating the management of collaboration between the design team members at different functional departments of a large-scale organisation located in distributed locations. The product data management and information sharing for designing consumer products are demonstrated. A primary focus of this research project has been the integration of the product development life cycle stages. Each life cycle stage effectively is an increase in complexity and details of the shared knowledge. Thus, this stage shows the representation of collaborative knowledge and products at increasing levels of complexity.

This stage starts with the initial investigation and examination of ideas for new consumer products. This then, through design iterations, results in individual tasks for produced products of the development. In this case,

Table 2 The components' properties

Component name	α-Symmetry	β-Symmetry	Length (mm)	Width (mm)	Thickness (mm)	A/B	A/C	Weight (grams)
Front cover	360	360	152.2	84	13	1.8	11.7	12.7
Adapter end	360	360	16.2	10.5	9	1.54	1.8	0.43
Spring	180	0	7	3	3	2.3	2.3	0.33
Keyboard	360	360	77	64	3.5	1.2	30.8	0.23
Spring foil	360	360	77	64	2.5	1.2	30.8	4.30
Plastic cover	360	360	79	69	0.35	1.1	225	1.27
Dome foil	360	360	73	63	0.5	1.2	146	0.54
PCB	360	360	86	75	2	1.2	43	13.26
Screws	360	0	6	3.8	3.8	1.5	1.5	0.32
Rear cover	360	360	152.2	84	16	1.8	9.5	8.30
Battery cover	360	360	62	33	2	1.9	31	1.27

linked data and products are the parts chosen for representation for their complexity of tasks. The linked hypertext has been further explored in the stage and a task hierarchy represented by means of a managed project outline.

An example of how conceptual design information is made available to a distributed product development team and coherently represented in a suitable context is presented in this section.

4.1 The procedures for product data management and information sharing

One of the critical aspects in the organisation's product development is effective and timely product data management and information sharing. In previous literature, it transpired that information sharing is done in a rather traditional way. E-mail is the most widely used tool for information sharing and discussion. Further, Outlook, Lotus Notes, intranet, phone and fax are used to communicate within and across project teams. The developed system is designed to perform the processes in which there are activities from finding a business opportunity to designing for manufacture. In terms of multi-site collaboration, the developed system provides an integrated product design studio for the design team available to share and collaborate in distributed locations to support information sharing and product data management. In addition, a cost system is being incorporated into design stages. This section describes some of the implementations that have been completed. They are the visual representation of product information, database management and design communication. One example, the discussion of design analysis of a scientific calculator, is carried out to ensure that the product is designed for the most economic assembly technique. The following are the main specifications of the developed system that are available, collaborating with team members through the developed system:

1. Before proceeding with the cost estimation and the advanced plan, the designer must create a solid model of the design to extract the envelope dimension of the component and its volume from the CAD system. An exploded diagram of the product was first created on a CAD system (in this study, AutoCAD) as shown in Fig. 5. It shows that the product consists of fourteen components and five different kinds of feature: two through rectangular slots, sixteen blind holes, four steps with round corners, four through holes, one tapping hole and ten rectangular pockets with round corners and that two joining methods were used. These were snapping and screw connections. The map in Fig. 6 describes the components for a scientific calculator assembly. The main concept in Fig. 6

Table 3 The analysis of the Scientific Calculator components for the robotic assembly

Component name	Vulnerable			Stiffness	Joining method	Holding down			Composing movement		Aligning difficulty		During feeding		Insertion difficulty	
	(A) Non-vulnerable	(B) Max. drop 200 mm	(C) Max. drop 50 mm	(A) Non-flexible	(A) Flexible	(A) Snap	(B) Screwing	(C) Peg-hole	(A) Straight line	(B) No straight line	(A) Easy to align	(B) Not easy to align	(A) Overlap	(B) Tangle or nest	(A) No resistance to insertion	(B) Resistance to insertion
Front cover	A			A	A	A			A		A		NO		A	
Adapter end	A			A	A	A			A		A		NO		B	
Spring	A			B	C	B			A		A		B		A	
Keyboard	B			B	A	A			A		A		NO		A	
Spring foil	A			B	A	A			A		A		NO		A	
Plastic cover	A			B	A	A			A		A		NO		A	
Dome foil	A			B	A	A			A		A		NO		A	
PCB	A			A	A	A			A		B		NO		B	
Screws	A			A	B	B			A		A		NO		A	
Rear cover	A			A	A	A			A		B		NO		B	
Battery cover	A			A	A	A			A		A		NO		B	

contains the link with which the sub-concept map is retrieved from the current context. The concept map in Fig. 6 represents a hierarchy. Each concept in Fig. 6 represents a procedure that is in turn linked to a dialogue;

2. The capability of the developed system is shown through the conceptual communication and storage of product data concerning the procedure of the product assembly. The assembly structure involves the sequence of and the relationships between single assembly operations. It is determined by the manner in which the product assortment and the product structure are built up from sub-assemblies and other components, which in turn determine the interrelationships between system components. The discussion of design analysis follows from the overview of all single assembly operations which are required to assemble the product and as they follow one another in time;
3. The establishment of the correct assembly sequence and the formation of sub-assemblies are important stages of design for assembly analysis. The development of the assembly structure, for the calculator, presumes that there is specific preference for the sequence of the assembling components. The assembly processes are as follows: (1) mount the 'Front Cover' on a fixture, (2) add to it the 'Adapter End', (3) the 'Spring', (4) and the 'Keyboard, (5) snapping the 'Spring Foil', (6) add the 'Dome Foil', (7) and the 'Plastic Cover', (8) snapping 'PCB', (9, 10, 11. 12) and tighten the four ' Screws', (13) snapping the 'Rear Cover', (14) and add the 'Battery Cover';
4. A selected representation of assembly plan is carrying on the scientific analysis as follows: (1) to select the most economic assembly technique, (2) to analyse the product for the selected assembly method, (3) to highlight the components that are candidates for redesign, (4) to provide redesign suggestions to simplify the assembly operations, (5) to estimate the assembly time and cost for the final product design;
5. Dialogues to facilitate standardised collaboration are associated with each node in a concept map. Depending on the context of the node, various input fields are completed;

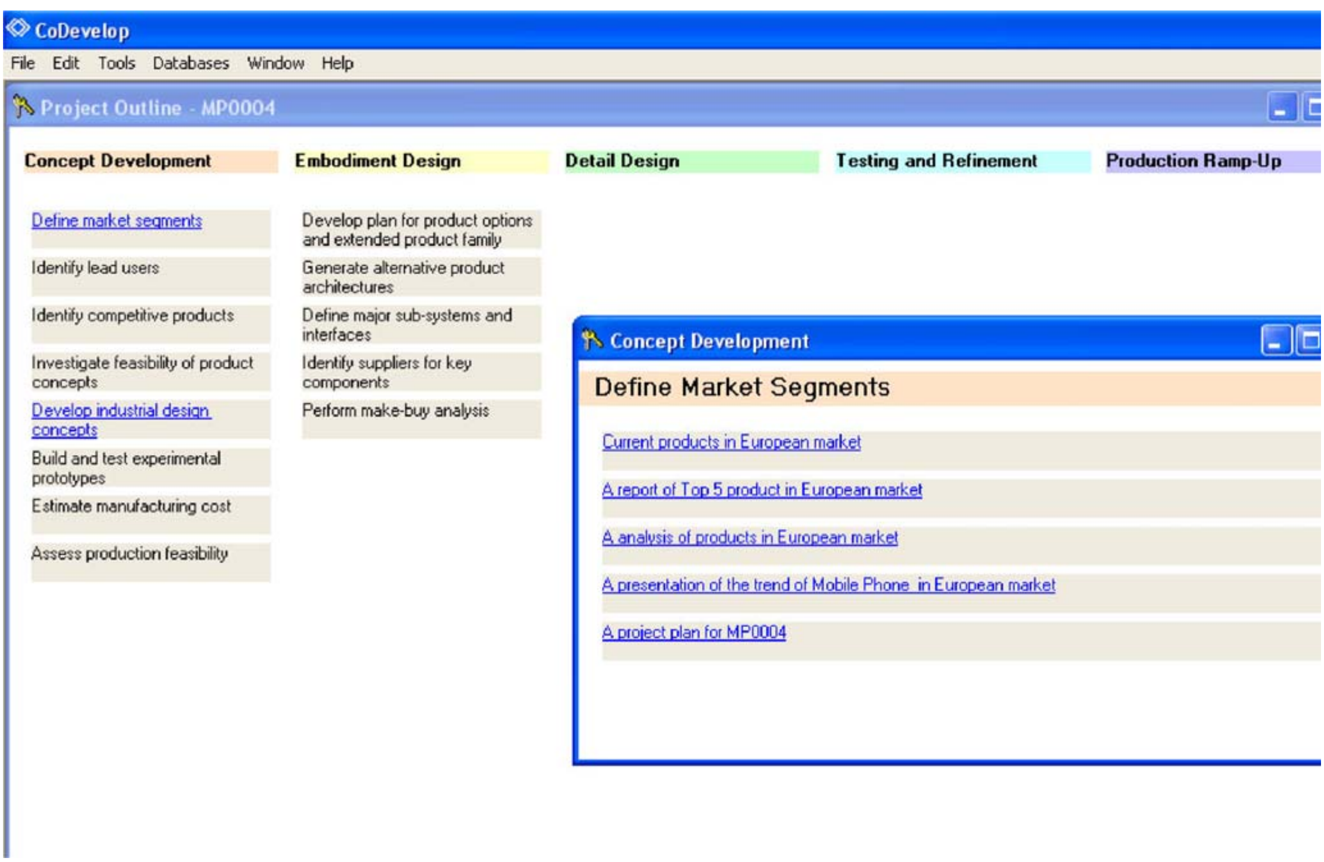

Fig. 7 Product data management

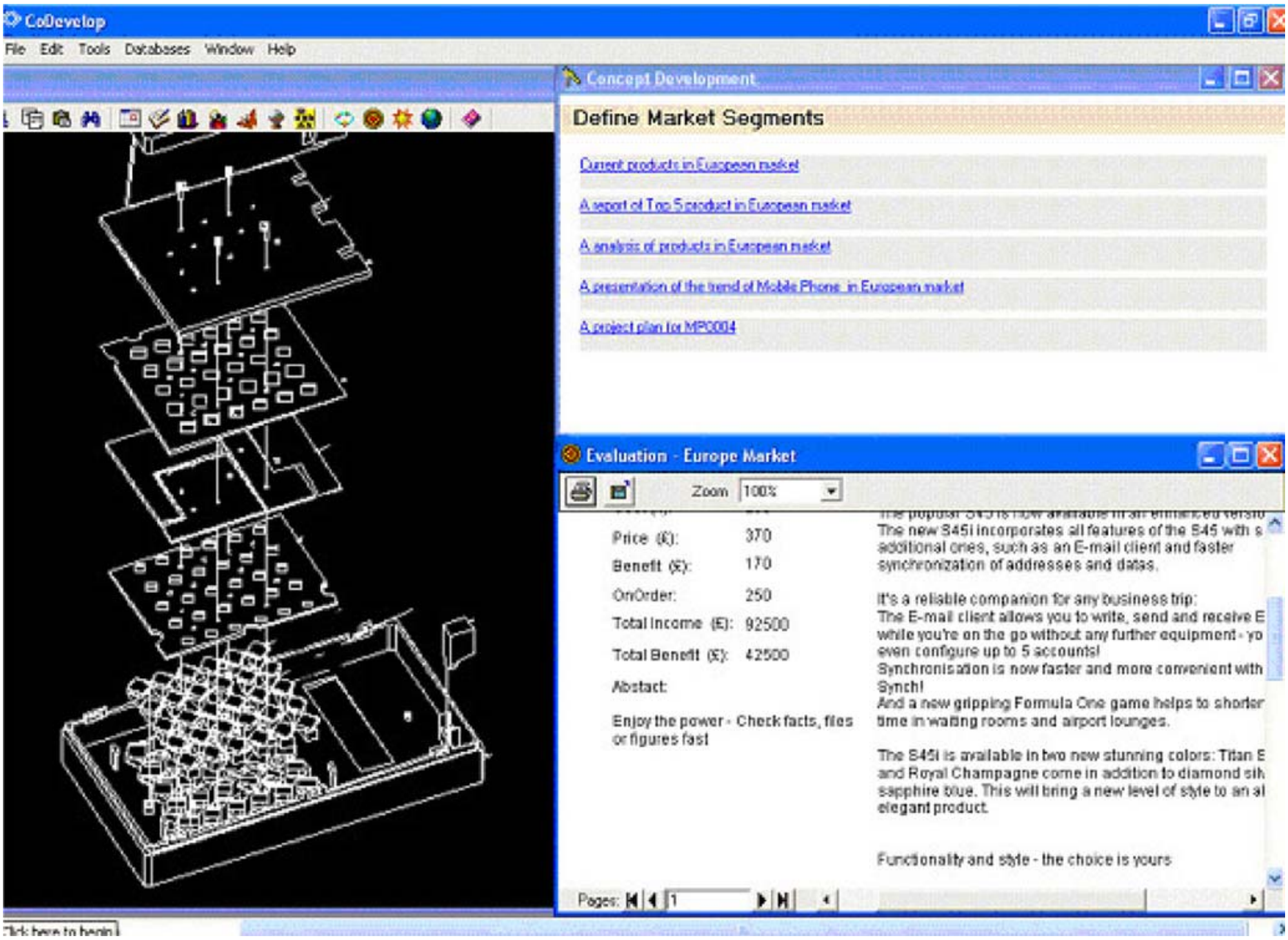

Fig. 8 Product data management-linked files

6. The industrial designer should be aware of the nature of assembly processes and should always have sound reasons for requiring separate components, and these will lead to higher assembly costs, rather than combining several components into one manufactured item. The reason for that early selection of assembly process being important is that manual assembly differs widely from automatic or robotic assembly in the requirements that it imposes on the product design. The software agent from the designer's local system is implemented for helping the selection of the most economic assembly technique. The technical data that were given by team members who are responsible, are shown in Table 1. According to the design product analysis and production parameters (production volume, number of components, etc.), the output from the software agent has recommended the robotic assembly system, as the most economic assembly technique for assembling the calculator and the outcome is saved as a image format and hyperlinked with the concept node. The procedures for assembly technique selection and assembly cost estimation are detailed in reference [22];
7. Further discussions of the design analysis of the product were: (1) to ensure that the product is designed for robotic assembly technique, and (2) to facilitate design improvement suggestions for ease of assembly by identifying weak points in the design. The analysis of the calculator design was still carried out using the third-party software agent. Evaluation score methodology was used to assess design quality or difficulty of assembly operation. In this technique, the design criteria for robotic assembly have been applied for each component. To start the analysis, the component's properties need to be identified and gathered from the team members who are responsible. The following series of dialogues represent the concept detail stored in the node describing the attributes of the design analysis as shown the component's properties in Table 2 and the analysis of the

scientific calculator components for the robotic assembly in Table 3. The design analysis dialogue is not required as the design analysis is a bottom level concept; there is no further sub-information to include;

8. All generated concepts are stored in a communication database and are also available to convert to a checklist as a document format;
9. The PDM module allows users of appropriate authority to upload or download the products of tasks, such as document or image, from a server to allow information sharing between other team members. The product data sharing was shown through the HTTP (hypertext transfer protocol) linked completed tasks which are done by other team members and are linked to external Web-based files (see Fig. 7);
10. The linking of the product data of the increasing levels of knowledge complexity demonstrates the integration of product development lifecycle phases. The integrated product development environment provides several tools for executing the linking of the product data without considering the file format used by the file creator, shown in Fig. 8;
11. The project manager is available to track the promised deliverables by team members via a PDM module;
12. Finally, asynchronous and synchronous collaborations are facilitated; the developed system provides the facility for real time and serial knowledge input.

5 Discussion

A Web-based integrated design system has been discussed that considers holistic product development to concurrent product and process design at distributed locations. The developed system is a prototype that breaks the geographical limitations for collaboration and unifies idea generation, concept development and testing, marketing strategy, business analysis, product development, test marketing and commercialisation. This is because this system uses a state-of-the-art Web technology that makes the product developing team available to collaborate and coordinate in any time and location. This system architecture supports the simultaneous use of the system by many users, who could be distributed geographically in real-time. The developed system provides the users with their familiar mechanism where marketing, design and manufacturing information could be disclosed, sorted and analysed in distributed location during the product development. Moreover, an integrated design studio allows designers the ability to share, discuss, and modify the design concept at an early design stage. In order to improve the effectiveness of coordination, the system also provides a communication media to make more effective the real-time interaction among the geographically distributed team members. The developed system has been validated through a case study. The result is successful to meet the requirement of the product development. However, this system still needs to be tested further by an organisation that operates in distributed locations. In addition, while the system supports the development of complex marketing, design, and manufacturing at certain area; more work is required to represent the complex conditions of such local legislation, culture, and environmental issues.

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