INTEGRATED DESIGN SYSTEM TO SUPPORT PARTNERING PRACTICE IN THE WATER INDUSTRY

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ABSTRACT: The Egan report on the UK construction has identified the traditional competitive tendering as one of the main causes for the poor performance of the industry. It recommends the use of supply chain Partnering to deliver valuable performance improvements. Partnering involves two or more organisations working together to improve performance through agreeing mutual objectives, devising a way for resolving any disputes and committing themselves to continuous improvement, measuring progress and sharing the gains. To realise the full potential of partnering it is necessary to implement an effective and reliable information infrastructure in support of integrated information management and exchange in the project process. This paper describes an on-going research project, GALLICON, funded by the Department of Environment, Transport and Regions (DETR) and a consortium of companies who are involved in the design and construction of water treatment plants in the UK. Its main aim is to develop an integrated design system which facilitates the collaboration and information sharing between the partnering organisations during the design of water treatment plants.

KEYWORDS: integrated system, information sharing, water industry, integrated project database

1. INTRODUCTION

Construction is one of the largest economic sectors in all the developed economies. For example in the UK, the industry had an output of some £58 billions in 1998, equivalent to roughly 10% of GDP, and employs around 1.4 million people (Egan 1998). The performance of the construction industry has consistently lagged behind other industrial and service sectors. In recent years as a result of a business down turn and increasing international competition, performance improvement is seen as a matter of life and death for many construction companies in the UK. The most distinct characteristic of the construction industry and also one of the main causes for the industry's poor performance is its fragmented organisational structure. The industry consists of hundreds of thousands of firms, over 90% of them are small and medium size with less than 10 employees. Most construction projects often involve an ad hoc team of 15-20 of these firms located at disperse places. The fragmentation often causes poor interdisciplinary communication. The problem is compounded by the widely adopted competitive tendering procurement method which results in project team changes from project to project. Similarly, the majority of the clients are one off clients. The unstable supply chain of the construction industry has serious adverse effect on its efficiency.

A typical construction project consists of many sub-processes often carried out by different professionals at different locations. Poor cross-discipline communication is not only a bottleneck for performance improvement but also re-enforcing the confrontational and blaming culture so common in the construction industry. It needs to be addressed urgently if the performance improvement demanded by Latham (1994) and Egan (1998) is to be achieved. With the increased use of construction software, the traditional cross discipline communication is increasingly manifested as an issue of data exchange and data sharing between different software applications. Unfortunately, because most of the software packages are developed by different vendors, they all have their own particular data format. To achieve data exchange, a data mapping mechanism is required between two applications involved in the exchange. Given the large number of applications used throughout the building life cycle, it is impractical to set up one-to-one mapping between all of them. A more efficient solution is to use a neutral data format as a medium for the data exchange. This neutral data format is an integrated data model which captures the full semantics of a building system and its components. In this approach, each application only works with a subset of the model. This subset is often described as an aspect model. Data exchange can be achieved between all the aspect models by mapping through the integrated data model.

This paper describes an application oriented research project which seeks to apply the integrated project database technology to the design and construction of water treatment plants. The main challenge for the study is not only to develop new technical solutions but also to ensure the solutions can bring business benefits to water treatment projects in practice.

2. SUPPLY CHAIN PARTNERING

During the last two decades, all manufacturing sectors have experienced various forms of business re-engineering. Many traditional supply chain relationships have been redefined. The AEC industry practice is also going through a transformation in recent years (Consultative Committee on Construction Industry Statistics 1994). Previously, a widely held view of the construction process is that it is different from other manufacturing industries because every product is unique. The conventional processes assume that clients benefit from choosing a new team of designers, constructors and suppliers competitively for every project they do. As a result of the repeated selection of new teams, there is little incentive for construction companies involved to invest and develop teamwork skills and innovation, both of which are vital to further efficiency improvement. Critically, it has prevented the industry from developing products and an identity - or brand - that can be understood by its clients.

The problem has been recognised and efforts are being made to improve the situation. One of the emerged solutions is the partnering arrangement between clients and contractors replacing the conventional competitive tendering. The key to the partnering approach is that a client and a contractor form a long-term stable relationship whereby the client’s new projects will be automatically awarded to the partnering contractor. Such an arrangement will enable the contractor and its sub-contractors to improve the repeated process and offer the client best value for money.

3. GALLICON PROJECT

GALLICON is a research project funded by the Department of Environment, Transport and Regions (DETR) and a consortium of companies who are involved in the design and construction of water treatment plants in the UK. These companies include a client, a contractor and a cost consultant firm. They have an existing partnering arrangement and are committed to form a stable supply chain relationship. One of the main obstacles they face is the bottleneck of cross discipline communication. Although the design, cost estimating and project planning tasks are carried out using computer software independently. Due to data incompatibility, the information exchange between the tasks is still done using paper medium. Given these tasks are often geographically distributed, this traditional paper based information exchange is often a cause for project delay and errors. Furthermore, due to the lack of integrated information management, during each project decision making knowledge is not captured effectively nor is it stored in an appropriate format which can be readily reused in future projects. The main aim of the GALLICON project is to develop an integrated information framework which will improve the communications and information exchange between the distributed processes of design, cost estimating and project planning.

4. ANALYSIS AND MODELLING

The aim of the analysis and modelling activities is to understand correctly the business processes and information flows of water treatment projects. Given the complexity of the subject, an iterative approach was adopted. Each cycle of the analysis consists of *Requirement capturing*, *Analysis and modelling*, and *Validation*. Requirement capturing is carried out through case studies and interview techniques. It involves the researchers identifying several previous and on-going projects and collecting project information. Interviews with the key professionals, e.g., designers, cost consultants and project managers, help to define the main project processes and the decision-making sequences. Based on previous projects' experiences, a combination of IDEF0 (Meta Software Corporation, 1987) and UML (OMG, 1999) methodologies are used to formalise the captured requirements. The IDEF0 model is more appropriate for communication with the construction professionals and the UML model is more suited for system design and implementation. Once the initial models are developed further meetings with the project participants are conducted to validate the models or else identify inaccuracies and requirements for further decomposition which will form the basis for the next iteration.

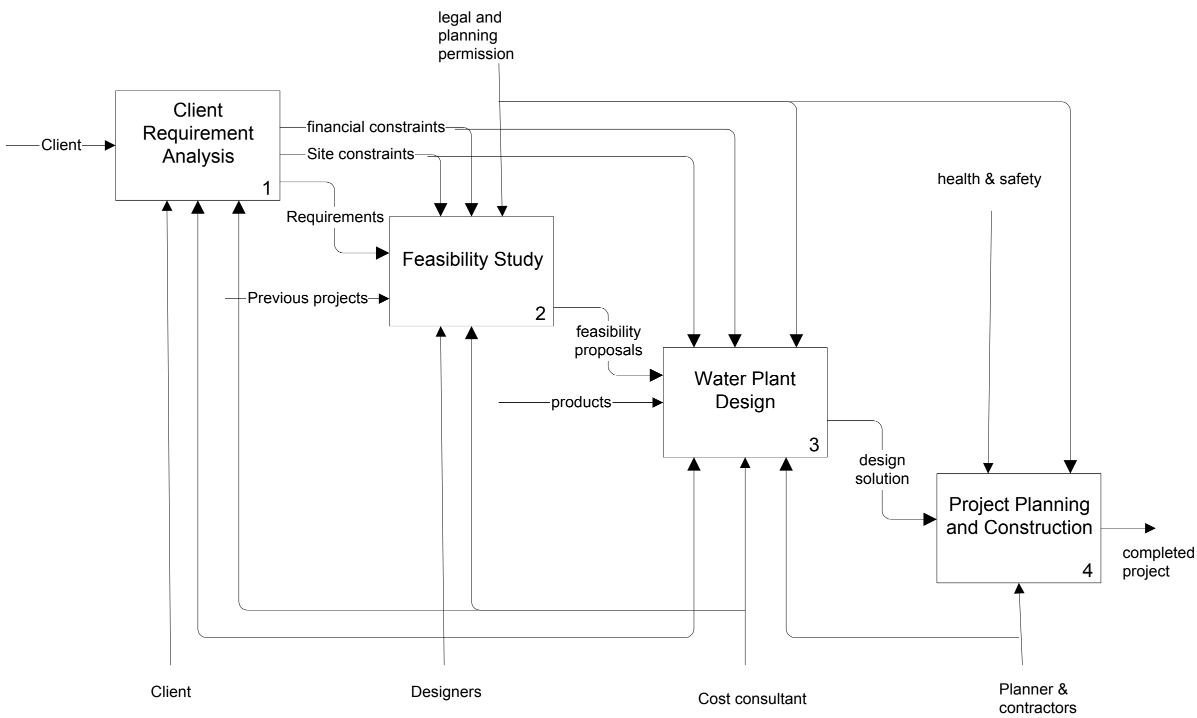

Figure 1. Top level IDEF0 diagram for the GALLICON project

Figure 1 shows the top-level diagram of the GALLICON process analysis for water treatment project. Following the IDEF0 paradigm each of the top-level activities is further decomposed into more specific activities. Overall there are four levels of decomposition and 175 activity nodes in the GALLICON process model. The full model covers the processes from requirement analysis to completion of post-project activities. The advantage of IDEF0 modelling is that the method fits well with the sequential process of construction decision making. The structure of input, output, constraints and support mechanism of each process is also easily understood by people without prior modelling skills. It is good at decomposing a complex process into more manageable smaller processes. However, because IDEF0 is activity oriented rather than object oriented, IDEF0 models do not help to define objects and relationships between objects. In GALLICON a complementary modelling methodology- UML is used to define the object data model.

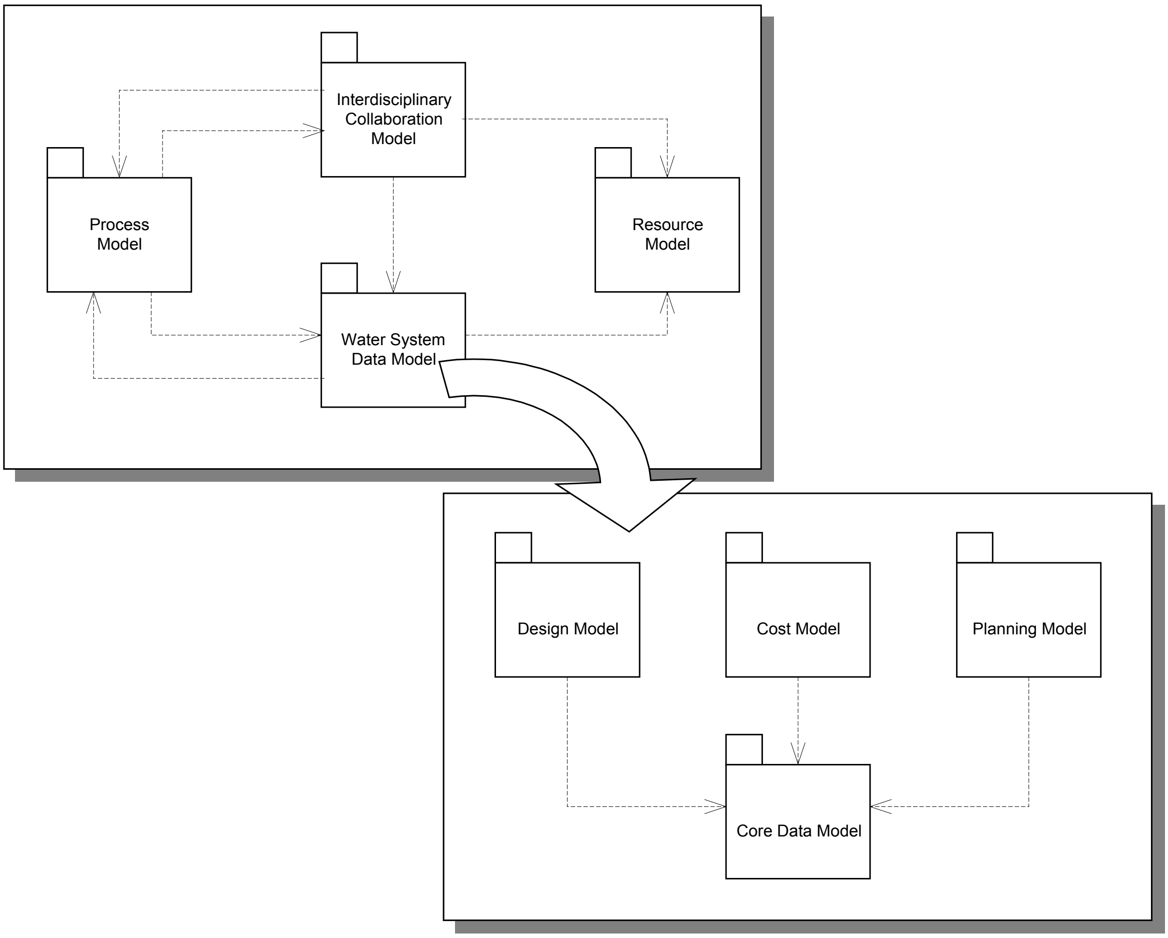

Figure 2. UML packages for the GALLICON models

The Unified Modeling Language (UML) is a relatively new modelling language for specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as for business modeling and other non-software systems. The UML represents a collection of the best engineering practices that have proven successful in the modeling of large and complex systems. The UML formalism organises models into logical packages. Each package groups a collection of classes or objects closely related to each other. Packages can be further decomposed into subpackages. The GALLICON analysis defined four top level packages (Figure 2), Interdisciplinary Collaboration Model, Process Model, Water System Data Model and Resource Model. The purpose of each model is summarised as follows:

- Interdisciplinary Collaboration Model defines the generic facilities, not construction specific, for collaboration between different people working on the same project. It includes actor and role as well as permission to use information.
- The Process Model defines the business logic behind the design process for water treatment projects. It identifies construction specific role and responsibilities and the decision making sequences. It makes use of the generic classes defined in the Interdiscipinary Collaboration Model.
- The Water System Data Model defines the objects of a water treatment system, such as tank, pipe, pump, material, etc. It is decomposed into Core Data Model, Design Model, Cost Model and Planning Model. Each subpackage except Core Data Model represents a view of a profession such as designer, cost estimator and project planner.
- The Resource Model defines some shared information resources such as materials, manufactured products, labour and equipment unit costs, etc.

Obviously, the whole model is too complex to present in this paper. Figure 3 shows a simplified view of the Interdisciplinary Colleboration Model. The modelling task involves identifying all the objects and their relationships as well as the functions for the main objects.

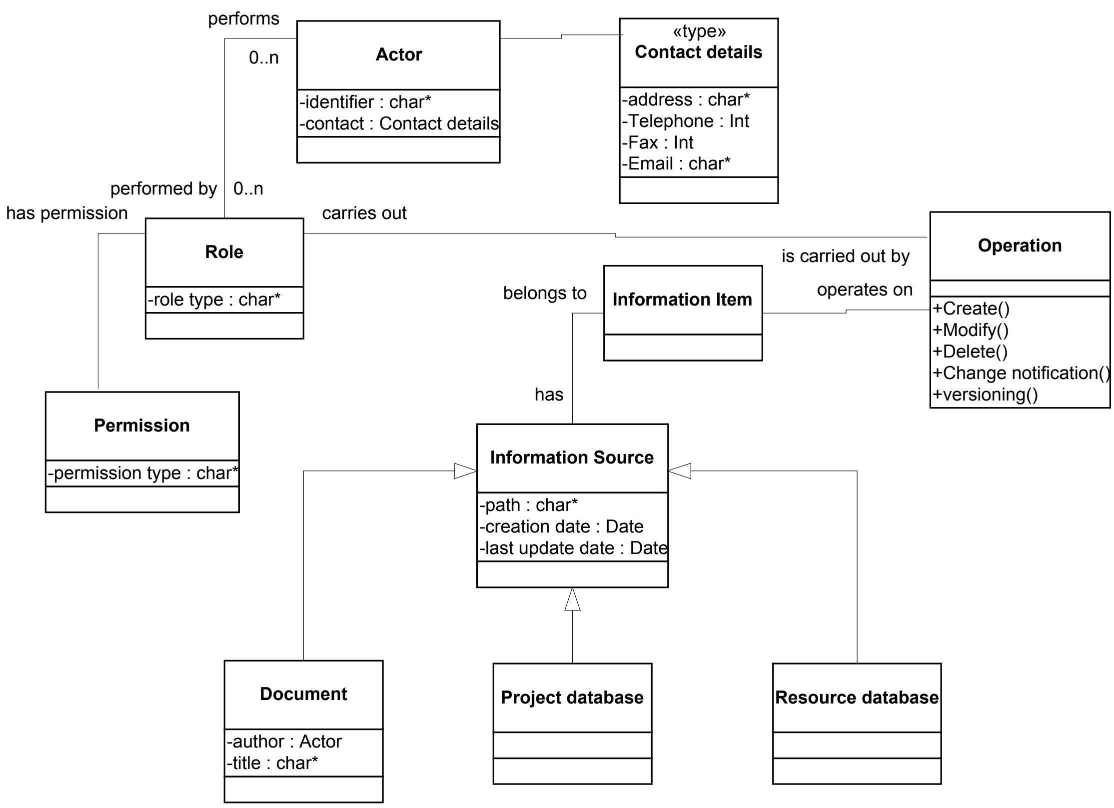

Figure. 3 Illustration of the Interdisciplinary Collaboration Model

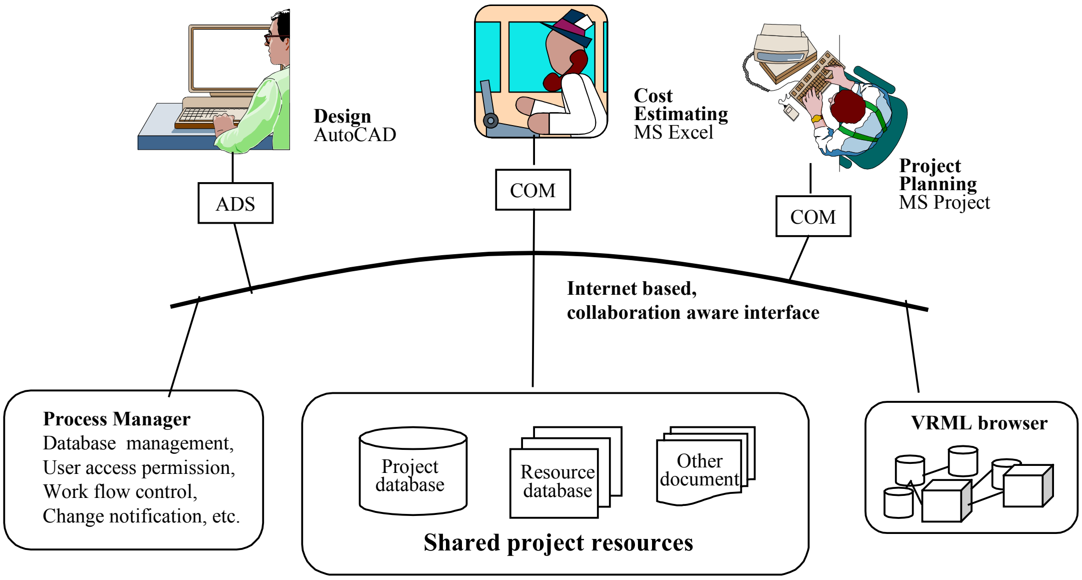

Figure 4. System architecture of GALLICON

5. SYSTEM ARCHITECTURE

Figure 4 shows the system configuration of the GALLICON prototype. It adopted a distributed architecture which consists of a repository of shared project resources, a Process Manager, interfaces to three third party software packages, and a VRML browser. The application software packages are used for design, cost estimating and project planning during water treatment projects. The project information is held in the project database which can be accessed by all applications of the system. The VRML browser provides a graphical visualisation of the project data which facilitates the communications between partners located at different places. The Process Manager controls the operation of the whole system. It is developed on the basis of analysis of business activities and cross-disciplinary interaction in water projects. Each of the system components is explained in the following.

Shared project resources. The shared resources include an integrated project database, databases of cost and materials and other project documents. The integrated project database is implemented using a commercial object oriented database system, ObjectStore (Object Design, 1997). A layering approach was adopted for the implementation. The first layer is ObjectStore database layer which provides generic functions for object versioning, locking control, client and server services, etc. On top of the database layer is a layer that handles GALLICON object creation, deletion and navigation. The implementation of this layer requires a GALLICON data model. The third and outside layer is an Application Programming Interface (API) layer. It defines a unified method for outside processes to interact with the GALLICON model. The GALLICON model was defined using an object oriented data modelling paradigm. The task involves first identifying all the objects of a water treatment system and their relationships, then examining their mapping with the IAI IFC objects (IAI 1999). The current release of IFC model does not cover water treatment domain. However, it is found that many objects defined in the IFC Shared Building Service Elements can be used for the GALLICON model. For example, GALLICON pipe object has a matching IFC IfcDistributionFlowElement object. Those objects with no direct appropriate match can also be made a descendant of IFC objects. For example, GALLICON SewageSeparator object is made a subtype of IfcFlowFitting object. Using this principle all GALLICON objects are fitted into the IFC object model hierarchy. The advantage is that general properties, such as cost and shape representation, are inherited from the top level IFC objects. GALLICON has a purpose built resource database of construction materials commonly used in water projects and unit costs of labour, plants and materials. It is also possible to use other resource databases as long as an interface link can be defined. In addition, the system provides a co-ordinated document management for other types of documents associated with a water project.

AutoCAD design tool. At present, the design of water treatment plants is usually carried out using AutoCAD. Because the existing version of AutoCAD is a graphic centric drafting tool, it only deals with objects such as point, line, face, solids, etc. On the other hand, the designers have to work with more complex objects, such as site, tanks, pipes, pumps, etc. GALLICON aims at bridging this semantic gap by integrating the “off-the-shelf” AutoCAD tool with the integrated project database. This is achieved through an AutoCAD Development System (ADS) program which can be loaded into AutoCAD and offers a new range of functions, such as “open database”, “draw tank”, “draw pipe”, “specify tank”, “save database”, etc. Using the customised AutoCAD tool, a designer is able to draw the design layout of a water treatment project and specify materials for all the components. Once the information is saved into the database, it will be available to the purpose built MS Excel cost estimating tool and MS Project planning tool.

MS Excel cost estimating tool. Microsoft Excel spreadsheet is identified as the cost estimating tool. A data mapping interface is developed using Microsoft Component Object Model (COM) standard between the integrated project database and the standard Excel application. COM is a protocol that provides a framework for integrating software components. The data mapping program reads data from the database, generates quantity take-offs and displays them in Excel. The user’s interaction with Excel is monitored by the program and the database is updated when changes are made by the user. In addition to the design data created by the CAD design tool, the cost estimating tool also needs unit cost information which is stored in a separate resource database.

MS Project planning tool. For the project planning tool, GALLICON has chosen Microsoft Project package. The interface between MS Project and the integrated project database is through a COM based link similar to that of the cost estimating tool interface. This link supports a bi-directional data mapping. It allows MS Project to read from the project database and create the work items and duration automatically. The planner can then use the full functions of MS Project to do the project scheduling. Finally, the result can be saved back to the database.

VRML browser. To ensure the success of the inter-disciplinary collaboration, a common visual representation of the project database is needed for participants located remotely. Virtual Reality (VR) has emerged as an ideal technology for this purpose. The Virtual Reality Modelling Language (VRML) is the WWW manifestation of VR. It is a text based file of definitions and geometry, specifying the composition of an image scene in 3D (Ames, 1997). This 3D scene can be viewed by a contemporary web browser equipped with a plug-in capable of understanding and rendering a VRML scene. The GALLICON prototype has a built-in VRML code generator which can create a VRML representation of any object with a shape representation. Using this facility a 3D model of the water project can be generated instantly and distributed across the Internet to the project participants and the wider audiences. Virtual Reality has always been looked at as a visualisation tool. This paper argues that VR should be used as a communication tool to convey more than visual information.

Product information costs, project progress, etc., can also be communicated using VR. Using web-based VRML facilities, the user can interact with the 3D models remotely using an intuitive interface. The VRML model acts as an interface to a sophisticated database, which will allow information to be shown graphically rather than searching through thousands of records or classes in a database. The user can click on a tank, pipe, etc., and get information about specifications, cost, time, health and safety requirements and other information. The GALLICON project has developed the VRML model to act as an interface to show design, cost and time information retrieved from the object oriented database. The user can select the desired information perspective to retrieve relevant information. GALLICON has proved that the use of VRML as a mechanism for visualising and retrieving information from a database is a powerful and useful tool for the construction industry as a whole. The simplification of user interfaces through the use of visual images is the way forward for an industry which is fragmented and information intensive.

Process Manager. The major issues of implementing an integrated system include user access control, change notifications, view integration, data consistency, etc. The chosen ObjectStore database for the GALLICON prototype provides the potential support for full concurrent engineering support at database, model even object levels. However, the process analysis revealed that concurrent access control is not the main concern of the industrial partners. The overlaps between the perspective models of the application packages are largely one application uses other's data as input. Therefore the major challenge of GALLICON is change notification and process co-ordination which are achieved through the Process Managers. The following scenario illustrates how the system operates. At the start of a new water treatment project, the project manager will set up the integrated project database and give all participants, designers, cost estimators, planners and clients, appropriate levels of permission of access. When a designer logs in he or she starts the design of the water treatment plant using a CAD tool. Project information, such as layout and material specification, is transferred to and stored in the integrated project database. The Process Manager monitors the progress of the design activity. At certain stage, a cost estimate is needed. The Process Manager will inform the cost estimator using a messaging system, who will perform the task using a cost estimating software and project data downloaded directly from the database. The cost estimator is able to see the exact status of the project from a graphic illustration of the project progress and project data using a VRML viewer. The designer and cost estimator can work collaboratively to modify the design and components specifications. The visualisation tools will facilitate the inter-disciplinary communication. When the design is near completion, the planner is given permission by the Process Manager to start planning. Again, project data are stored in the database and readily available to the project planning software. The benefit for the client is that they can monitor the project decision making process, know the design they are going to get, how much it costs and how the on-site operation is scheduled to completion.

6. DISTRIBUTED COLLABORATION WORK SUPPORT

The GALLICON system intends to support the collaboration of a multi-disciplinary project team located in different parts of the country; some may be on-site, others located at an administrative office. What each has in common is access to a computer and the Internet. Computer based communication and collaboration tools will then be used to connect project participants and support the information flow and processes of the design and construction activities. At present, a WWW based virtual workspace is implemented based on Basic Support for Collaborative Work (BSCW) prototype (Bentley, 1997). It enables remotely located partners to exchange textual messages, and share workflow information. It also co-ordinates the access of the integrated project database using the process model knowledge. Additional functions will be added in the future to support more interactive user collaborations.

7. MEASURING BENEFITS

The industrial partners of the project are understandably interested in measuring the benefits of the developed system in real projects. In fact it has been recognised that the lack of ability to quantify the benefits of potential IT innovation is one of the most common barriers for construction companies to make IT investments. In the tight profit margin construction industry a usual trap in measuring IT benefit is to focus purely on monetary terms, i.e., how much money the system will help to save. IT investment should be considered as long term investment with multi-facet benefits, such as improvement in client satisfaction and perception, gaining competitive advantage, more efficient business process, etc. Baldwin (1999) presented a practical methodology for measuring the benefits of IT innovation. It proposes that any assessment should be conducted in three areas, *efficiency*, *effectiveness* and *performance* (Table 1). Efficiency is financially measurable and is represented by money. Effectiveness is measurable but not in monetary terms and is represented by improved operation. Performance is not directly measurable in quantifiable terms but can be judged qualitatively in influencing long-term business performance by increasing profit and market share.

Table 1. Benefits measurement of IT innovation

Benefit Type	Indicator	Benefits
Efficiency (£)	These are quantitative indicators that will generally be measured in cost or time.	These will be the value of the change in the quantitative indicators between the pre and post implementation stages
Effectiveness (Q)	These are qualitative benefits that the system may bring. They may not have a direct monetary value, but improve the quality of the way a process is carried out	The qualitative benefits will be described. This could include customer satisfaction or an improvement in quality.
Business Performance (S)	These are benefits that reflect wider improvements in the process that may reflect long term strategic goals.	These are broader qualitative issues that will be recognised at the strategic level such as development of IT strategy or improved long term competitiveness.

At the moment, the GALLICON system is still at the development stage. Preparations are being made for the benefit measurement task. A comparative case study approach will be adopted using previous completed projects. The analysis and modelling tasks described in section 4 has established the current processes of several water treatment projects with the construction professionals using discrete software tools. The same projects will be used in simulated tests using the developed GALLICON system. The tests will involve a series of role-play sessions participated by the original project team members. The tests will reexamine the decision making process of the previous water treatment projects and identify what, how and the extent the current process can be improved by using the GALLICON system.

8. CONCLUSIONS

With the continuous development in product data technology, such as data modelling and data exchange standards, and the improvement of database capability, the potential application of an integrated project database in construction practice can no longer be ignored. The industry is also eager to capitalise on this potential. GALLICON is an attempt to apply an integrated project database to the design and construction of water treatment projects. The challenge of the project is not only to develop a technical solution of an integrated system but also to ensure the system can support the urgently needed improvement in inter-disciplinary communication between partnering companies. GALLICON is an on-going project. This paper described the process analysis work and the development of a prototype. Tests will be conducted shortly to evaluate the true benefits of an integrated design system.

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