Concurrent Engineering Support with an Advanced DMS

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1. Introduction

This paper reports on the DMS (Document Management System) development in the EC funded project ToCEE (Towards a Concurrent Engineering Environment) in the context of its support for concurrent engineering in the construction industry (ESPRIT 1995). The usage scenarios described in this paper highlight how a DMS could be used within the life-cycle of a construction project to engender concurrent work practices. This includes not just parallel working, but the DMS's support for co-operative and collaborative working practices.

1.1 Concurrent Engineering

One of the major measures of the benefit of a concurrent engineering environment is its level of support for co-operation and collaboration between all participants in the project. The ToCEE project delivers an infrastructure which aims to engender better co-operation and collaboration with a project through the provision of open interfaces to all participants' organisations and also through an open interface to all services provided to the project. This allows controlled access by any participant to all levels of information in the system, whether that be the evolving product model, the state of the process management system, or the documents held in the project. Figure 1.1 shows the general framework of the ToCEE system in relationship to the clients and services involved. The server end of ToCEE ties together the full set of product, process, document, regulations, and conflict management systems from the involved participants to be visible through a single interface. Then from the client's end it is possible to access this unified set of services without regard to the location of any of the services or their information. Figure 1.1 shows the interfaces currently supported in ToCEE, which are via e-mail requests, through an Internet browser, or through tailored wrappers around existing design tools.

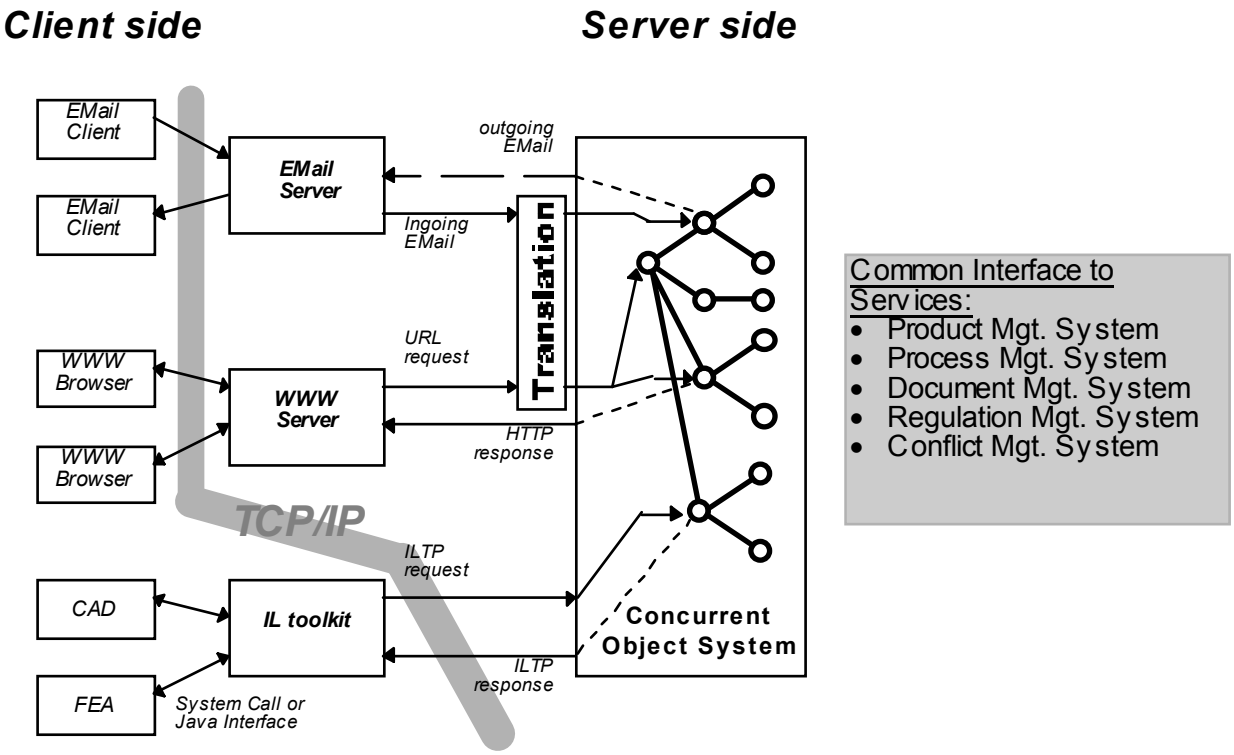

Figure 1.1 *The ToCEE system framework*

One of the servers to be implemented in ToCEE is for a DMS managing all project documentation and communications (see section 3 for a full specification). Previous papers have detailed the data model of the DMS (Amor and Clift 1996) and the range of services that the DMS server should offer to its clients (Amor and Clift 1997). This paper describes the total benefits that could be achieved through close integration between the DMS server and all other components in the concurrent engineering environment.

2. Existing DMS Systems and Projects

The existing systems summarised in this section combine the two aspects of document management and information logistics into a single system. This is in contrast to the approach taken in ToCEE where the document management system is treated as a single entity independent of, though with interfaces to, the informational logistics system. The information logistics system will implement the transport of electronic information between modules in ToCEE and manage the flow of control in the running project. With the ToCEE approach of a totally generic document management system it will be possible to utilise the implemented document management system with any integrated system in which the scope needs to be extended to documents.

2.1 Electronic Document Management System (EDMS) and Product Data Management System (PDMS) properties:

The major services offered by EDMSs for engineering and construction are: the ability to manage CAD files; document capture through scanning and conversion; folders or cases for handling complete projects; recording document workflow to allow documents to be routed to users; distributed RDBMS for interoperability; integration of other databases and computer networks; high security control; ability to handle large numbers of documents (in the hundreds of thousands); and the flexibility to manage compund documents of various types.

PDMSs have the properties of an EDMS as well as further product specific functionality, the major components of which are: configuration control for products and assemblies; management of relationships between items (e.g., CAD and word processor files); control of variants versus standard products; change impact assessment and management; and improving the flow of application data.

Though there are over a hundred readily available commercial systems (IIC and Cimtech 1996), which, though aimed at engineering domains, have had very limited take-up in the construction industry. Indeed most of the commercial EDMSs are aimed at individual firms, and the total management of documents inside the firm, rather than at a project level with the recognition of multiple external partners needing to collaborate. The commercial EDMS vendors would appear unaware of previous research into integrated design systems in the construction domain so their products tend not to support connections with product models. Indeed most systems treat documents and their management as a totally disparate field from product modelling, though there are enormous overlaps in the information manipulated in both of these areas. One of the newest systems currently being targeted at construction is BT Construct (1997), which is based upon Lotus Notes. Though this system does not manage documents and versions as would be expected in a full EDMS, it does manage much of the process and communication-related aspects of a project in a manner closely tailored to the UK construction industry's needs.

2.2 Research EDMS and PDMS

There has been very little previous research into the theoretical aspects of DMS. It has appeared as a commercial technology without a theoretical foundation, unlike for example, relational database management systems. This helps explain the wide variation of supported document types and document models that can be found in the various commercial offerings. It also leads to the situation where there is no interoperability between various EDMSs. This will be a barrier in the construction industry where groupings of partners are

made at the start of a project, and where the various partners may be using different EDMSs (however, see CONDOR below). There have been a few research projects examining theoretical DMS for the construction domain. These projects are described briefly below:

Related research projects are described in Turk (1994), Björk (1994) and Turk et al. (1994). These projects operated on the assumption that as a preliminary means to achieving Computer Integrated Construction (CIC) a construction document management system (CDM) could be constructed. The CDM is seen as a short term solution, being replaced by full product management systems when the technology matures. A strong case is put for the need for explicit research work on development of CDM systems for the integration of documents within single projects across organisational boundaries. Mokhtar and Bedard (1994) propose a central database as the source of all technical documents to reduce the estimated 50% of problems in buildings which arise through decisions and actions taken in developing working drawings. They envisage such a system helping through the production of integrated documents, through quicker communication of documents and through the production of document types which span disciplines. However, it is clear that different discipline's views of a proposed building are irreconcilable with computerised tools, so even an integrated product database will not provide the ability to reconcile all views. Armstrong and Lockley (1994) propose an integrated document kernel (IDK) with a very similar structure to the COMBINE framework (Augenbroe 1995) in which they were involved. Their work uses generic models of documents to demonstrate how a structured approach can facilitate the neutral exchange of certification information between applications using the STEP physical file format. This was prototyped for off-line data exchange between applications and their IDK. As with the COMBINE project a SGML Document Type Definition (DTD) model was developed to link product model information in the documents manipulated. The most recent project in this area is the EC funded CONDOR project (Rezgui et al. 1997). This project aims to specify a unified interface to DMS systems so that the problem of multiple systems in use by the organisations coming together for a project can be overcome. The final system will look like a single DMS, though requests related to documents could be propagated to a wide range of systems sited in different organisations.

3. Documents in Construction

The meaning and scope of the word 'document' in the traditional design and construction processes was always clear. A document was any collection of paper that related to a project and the physical nature of paper helped define its status as a document. With the advent of electronic representation of a traditional paper document, the definition of a document becomes blurred. Some paper documents are not currently able to be sent electronically (e.g. standards) and some electronically sent documents have not been considered documents in traditional construction practice (e.g. faxes, e-mail, and verbal instructions).

The ToCEE team was also concerned that the term 'document' conjures up visions of mountains of paper and it has therefore been defined by ToCEE as an 'information carrier.' This term is used for any exchange of information from the issue of a brief, drawing, specification, letter, calculation, approval, contract, change order etc. This would typically be in paper format for most projects from any sector, plus e-mail. There are a number of documents traditionally generated and stored in paper form for construction projects as shown in Table 3.1.

Type	Author	Legal / contractual status
Brief	client / owner	high
Contract / commission	client	high
Drawing	designer / contractor	high
Specifications	designer	high
Bills of quantities	quantity surveyor	medium
Tender documents	designer	high
Valuations	quantity surveyor	medium
Payment certificates	designer	high
Program / schedules	contractor	high
Calculations	designer / contractor	medium

Site diaries	supervisor / contractor	medium
Change orders	client / designer / contractor	high
Progress records	supervisor / contractor	low
Claims	contractor	high
Letters	all	high
E-mail	all	low
Fax	all	low
Request for information	contractor	medium
Confirmation of instruction	designer	medium
Notices	client	high

Table 3.1 *Standard documents in a construction project*

For construction projects in which the design has often not been completed until hand-over (or beyond), forms of day-to-day communication need capturing. These include those shown in Table 3.2, all of which have contractual implications. For a DMS to be taken up by the construction industry, it will need to capture these issues if it is to provide added value to the present paper based system.

Type	Author	Legal / contractual status
Phone	all	low
Verbal order	client / designer	medium
Advice	all	low
Video / progress photos	all	low

Table 3.2 *Communications in a construction project*

4. Construction Process Requirements for DMS

Construction projects are characterised by their one-off nature and the rapid assembly and disassembly of the project team, many of whom join during the project and depart before its completion. Many construction organisations are very small (1-2 persons) and may only be formed for the particular project. Even some of the larger organisations have failed to embrace the idea of electronic document management and interchange for several reasons but mainly because there is no industry accepted standard, incompatibility between systems adopted by organisations, and penetration is limited so that paper versions are needed at all times.

Current practice therefore is for all documents, even those that have been generated or transmitted electronically, to be stored as paper for distribution and legal or contractual purposes. Some larger organisations handle internal correspondence and drawing transfer between other company offices electronically. Future developments coupled with the use of electronic document management will need to address the following issues:

- **Common file format**. An industry accepted and fully adopted standard would greatly assist in setting up protocols for every new project and team.
- **Document access management.** Control of and authority for access to documents for read only, printing, and modification. Access should be recorded and identity noted.
- **Version management.** A record of every version (revision) of a document to be retained, be identifiable, and both the latest and earliest version(s) must be retrievable.
- **Search functionality.** Full text search functionality in text based documents must be provided. The descriptive data sets identifying a document would include information such type, project contents, responsible person, date (created/sent), version etc. to ensure alternative retrieval routes.
- **Electronic signature.** To satisfy legal and contractual aspects.

- **Shared databases.** For large organisations it is important that the DMS databases can be shared by several users.
- **File locking.** Only one alteration to be permitted at one time.
- **View / levels.** Parts of a document e.g. a drawing, must be capable of being viewed without having to call up the whole document
- **User friendly.** The user new to the system should only require a short training session - hours not days - and be site based. There should be immediate and tangible benefits for an organisation with improvements to the design, construction and maintenance processes and a saving in administration and management costs.

5. Demonstration of Benefits of an Advanced DMS

This section looks at the benefits which could be derived from an advanced DMS. The majority of what is described here is a future look, though in many cases the individual tools exist. Where the tools do already exist there are no current linkages between the tools described, or the tools described are not widely used in the construction industry.

5.1 Standard DMS Functions

There is a range of functions available in most standard DMSs which would provide benefit for the construction industry in the short term. However, as there is a very low uptake of DMS in the industry these benefits are not realised. The short term benefits which could be realised by utilisation of a DMS are mostly in the automation of non-value adding processes, e.g., automatic forwarding of documents to a set of team members on completion of a particular process or activity. Standard functions could also automate many of the tracking and verification activities required for dispute resolution by recording who received what documents, at what time, and by recording when the recipient opened the document. Standard functions will also allow security to be implemented through digital signatures to ensure that original versions can be identified and encryption should be used to ensure that unauthorised access to documents can be controlled.

5.2 Tracking and Monitoring Against Activities

The first part of the document, process, and product triangle comprises the connections between a document and the activities which went into the document creation. Documents are part of the input to the majority of activities and are part of the output of many activities or processes in a project. This ties to current work in the development of generic process maps for construction (BAA 1996) which are then specialised down to the actual project level with known teams and responsibilities. Current work on standards, especially the ISO-STEP Building Core Model (ISO 10303-106 1997) and the IAI-IFC version 1.5 (IAI 1997), provide the representational capability to manage the connections between process and related documents and products. However, tools which take advantage of these structures do not yet exist.

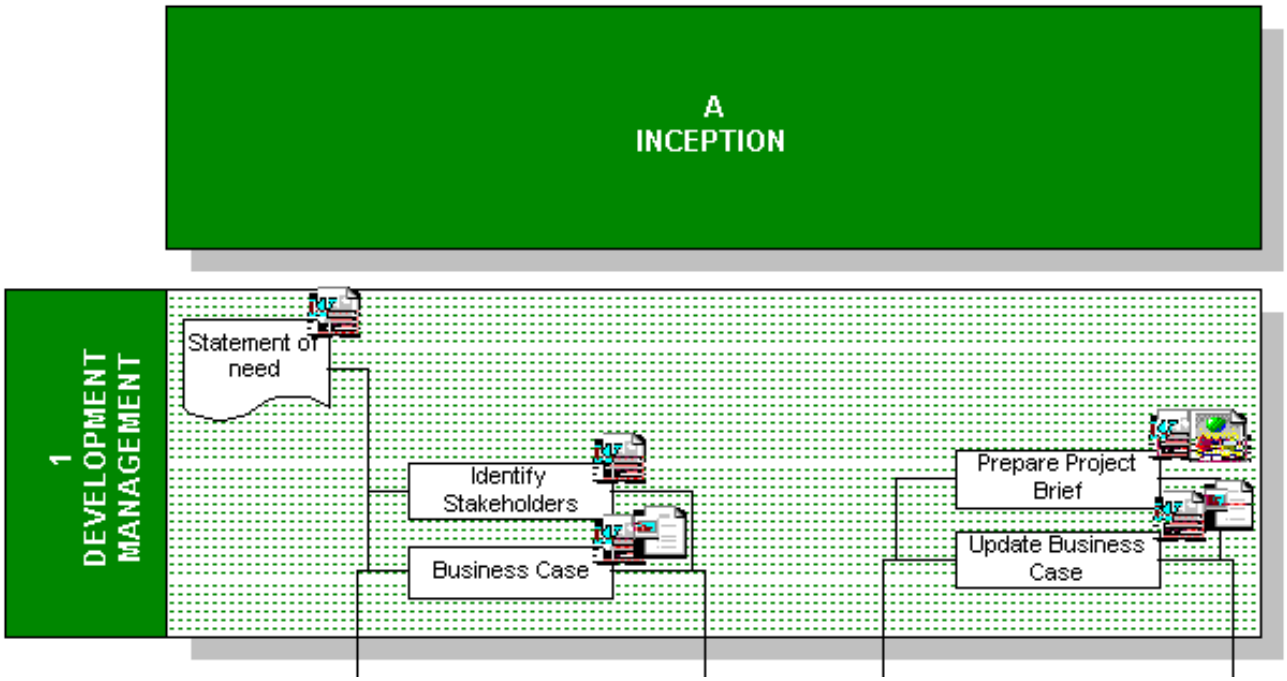

Figure 5.1 *A process map specialised for a particular project*

Figure 5.1 can be used to demonstrate how such a process map can be used either for current working, for checking on past work, or for a look-ahead to future work requirements. Figure 5.1 shows part of the detailed process for a construction project with processes to be completed and the flow of control between the processes. In this view it also shows the documents which feed into each process and those which are created during the process. In this view the user can inspect all of the documents which fed into the process and which came out, in this case a series of Word documents, CAD detail drawings, and a VR mock-up of views when passing through the building.

With an active process map the user is also informed of the running processes (those which are shaded) and can see the status of documents and models (completed, being worked upon, and not started) which are being created or modified during the process. In the future view the user can identify all documents which must feed into a process and determine from which processes these documents will be created, and hence what still needs to be completed before the examined process could be activated.

These process maps allow top level general information to be viewed as well as the ability to drill down to very detailed process specifications. At the top levels what is shown are the documents which feed into any of the processes encapsulated by a top level general process, and any outputs from the lower level processes which feed into other processes further down the line. That is, these process maps show the document interfaces between processes, either aggregated at higher levels, or in great detail at the more detailed process level.

In terms of enhanced co-operation and collaboration this allows users to identify what is seen or required for various processes by all of the participants in the project. It allows them to view the ongoing work inside a process and see where their inputs feed to other participants in the project.

5.3 Tracking and Monitoring Against Staff - CALIBRE

Hard facts about on-site productivity are notoriously difficult to come by. Every project and site is different and until recently there has been no simple way to consistently measure who is doing what and how much their activity actually contributes to advancing the project.

The Centre for Performance Improvement in Construction (CPIC) at the Building Research Establishment (BRE) in the UK has developed CALIBRE (1997), a simple, effective tool which maps site processes. At regular intervals an observer tours the site and records the tasks being undertaken by each operative against standard codes developed by CPIC. The data is captured on a hand held computer and downloaded for analysis to identify:

- added value time - making the building grow
- preparation of materials, etc. support time - supervision, testing etc.
- statutory time - meals, H&S related work
- non-added value time - not working, correcting work etc.

Information can be compared on day by day, site by site and supplier by supplier basis for any combination of work, area, task, activity and/or operative. Data is also downloaded to CPIC to feed their national database of performance measures, benchmarks etc. to generate periodic and end of project reviews.

5.4 Legal Admissibility

Verbal instructions issued on site have always been a breeding ground for legal and contractual wrangles. Contracts usually have a clause providing for a maximum time by when a verbal instruction must be confirmed in writing, often by the receiver of the instruction back to the instructor, who of course can query it. As often as not the work will have been started before the written confirmation has been generated. This gives the person carrying out the work the opportunity of matching or revising the original instruction to the actual work carried out. This not surprisingly leads to dispute.

There is emerging technology that should now resolve this in the form of hand and palm held computers that can communicate not only with each other via infrared but with head and site office PCs via modem so that the whole team can be immediately appraised of the instruction and provide the necessary support, or countermand it if there are wider implications not appreciated on site.

Telephone conversations pose similar problems and require confirmation if a contractual event, such as a request or instruction is included. Actual recordings are not considered viable - they are time consuming to review and are treated with suspicion. However the fact that a phone to phone connection was made, when and for how long is commonplace for billing purposes. Obviously the nature of the conversation is not recorded or even if anything was said at all.

E-mail has the advantage of being relatively easy to operate and the system can record that it has been received. It should not be difficult to note that it has at least been read by requiring an acknowledgement.

Site diaries are kept by the client's site representative and are often submitted as supporting evidence in case of disputes. These have traditionally been in hard copy format (like a ship’s log) to be inspected by the client's contract supervisor during site visits. Items recorded will include delivery of materials, labour on site, inspections, visitors, site activity, weather conditions, stoppages, etc.

Diaries are often backed up with site progress photographs normally taken from fixed locations and on a regular basis e.g. weekly or monthly unless specifically requested. Although CALIBRE will pick up some of these issues and download the data the remaining diary type information would be invaluable in providing an up to date picture of site progress. A digital camera used by the CALIBRE inspector could provide a useful and accessible view for the off-site team and provide supporting evidence for contractual debates.

Regular daily photographs linked to activities will also provide a useful record of how the building was put together, where services are buried and how to access or dismantle parts of the building for future maintenance, replacement and refurbishment.

5.4.1 BS PD0008

The electronic production and storage of documents has become common practice in the manufacturing industry and is expected to be so in the construction industry and will be increasingly used for business transactions such as ordering materials and plant.

The BSi Code of Practice 'Legal Admissibility of Information Stored on Electronic Document Management Systems (BS PD0008 1996) covers issues such as systems planning, implementation, initial loading, and procedures for using the system. It pays particular attention to setting up authorised procedures and subsequently the ability to demonstrate, in a court of law if needed, that the procedures have been followed.

The Code notes that image-processed documents are currently treated in the same way as photocopies or microfilm - i.e. as secondary evidence. In the adversarial legal system, the other party may try to discredit the integrity of the electronic document and the system on which it was recorded, as well as to dispute its content. There is a long tradition of trust in paper based documentation and limited knowledge, and therefore limited confidence of electronic methods. In cases where an electronic document has been submitted, the Court will want to question its history in order to evaluate its validity and evidential weight.

5.4.2 Building hand-over

Recent regulations, the Construction (Design and Management) Regulations 1994 (CDMR 1994), have created new legal responsibilities for clients and their consultants and contractors when undertaking most forms of construction. The construction industry has an unenviable track record when it comes to health and safety and CDMR aims to improve this, not only during construction, but also when carrying out the maintenance, alteration, refurbishment and ultimate demolition of the building. A Health and Safety file is prepared during the design and construction of the building containing information for safe occupation and is handed over with the building to the owner. This is a legal requirement and is accompanied by a considerable amount of drawn and manufacturers' information which is rarely structured in a form that is useful for the Facilities Manager (FM).

CAD drawings often lose attribute data if they are transferred to other applications such as those operated by the FM. The FM application will only use the final versions of design drawings and rarely needs access to earlier versions. Layering the information for FM use will ensure the right level of data is transferred at hand-over and hopefully cut out the huge mass of superfluous information.

5.5 Impact of Updates

An electronic document management system can automate many document management tasks such as logging document creation and modification times and generating version numbers for modified documents. If every transfer of information is accomplished through a set of documents, the following should be managed by the system:

- ascertaining the relationship between
  - a product and the documents it is referenced in
  - a document and the products referenced in it
  - an activity and the documents utilised during its execution
  - a document and the activities it is referenced or used in
- determining the reason for particular design decisions from related documents
- representing
  - the history of document revisions
  - relationship and legal status of a document
  - the current actor working on the model
  - the modifications made to a document by an actor
- tracking the documents which feed into an aggregated document

The system need not track all likely document types, but it must be capable of representing all types. It must be possible to specify what types of document will be tracked for a particular project. For any particular set-up of a DMS it is then possible to identify what impact a change will have on the other participants in the

project at that time. For example, when modifying a specification document it will be possible to identify the portion of the product model which will be impacted, and hence the other participants who will have to re-check their work to ensure the project requirements are still met.

5.6 Product Model Views

The final part of the product, process, and document triangle is the possible linkages from product models, and the tools which manipulate product models as part of the design and construction process, to the related documents and processes. To this extent all product information should be able to navigate a user through to the related documents and processes. Current work on standards, especially the ISO-STEP Building Core Model (ISO 10303-106 1997) and the IAI-IFC version 1.5 (IAI 1997), provide the representational capability to manage the connections between products and related documents and processes. However, tools which take advantage of these structures do not yet exist.

For example, in a CAD system it should be possible to select a single element (or a whole sub-assembly) and determine which documents refer to, or impact on, the selected element. These documents would provide information on constraints on the element, e.g., signed off specifications, as well as preferences for its design. At a later stage in the building's life, for example during facility management and maintenance, the documents would provide information on the original specification, tenders, and as-built drawings. This access to the document trail helps to identify who has been (or is currently) working on the element selected and what decisions have been made which may impact on the work that is currently being performed.

In terms of enhanced co-operation and collaboration these linkages provide users at all stages of a project with directed access to all information which relates to various portions of the building, no matter where this information might be stored. This can help ensure that all participants in a project are aware of the decisions which affect their work and are aware of the current set of constraints which limit what they are able to do in their work. In terms of managing liability in a project it ensures that all participants are aware of the constraints on their work and at what stage of finality the portion of the project they are working upon is currently at.

6. Conclusions

The DMS described will support the ToCEE aim of co-operative and collaborative working by ensuring access to the most recent version of all relevant documents for all parties in the project. The advanced DMS system described here will address the enormous administration costs associated with document handling in the construction industry (estimated at 30-40% of an engineer's work effort). This system is independent of team and organisational boundaries, and hence allows immediate notification and access to new documentation, for the whole project team. It also ties closely with all process aspects of a project over its whole life, along with links to products, and support for legal admissability.

It seems that the construction industry is ready to embrace IT, but is looking for an holistic approach. The fragmentary nature of the industry requires a more standardised approach. ToCEE will provide methods and guidelines for reducing the sequential approach to design and construction by encouraging collaborative working.

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