ELECTRONIC DOCUMENT MANAGEMENT IN CONSTRUCTION – RESEARCH ISSUES AND RESULTS

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SUMMARY*: Electronic document management (EDM) technology has the potential to enhance the information management in construction projects considerably, without radical changes to current practice. Over the past fifteen years this topic has been overshadowed by building product modelling in the construction IT research world, but at present EDM is quickly being introduced in practice, in particular in bigger projects. Often this is done in the form of third party services available over the World Wide Web. In the paper, a typology of research questions and methods is presented, which can be used to position the individual research efforts which are surveyed in the paper. Questions dealt with include: What features should EMD systems have? How much are they used? Are there benefits from use and how should these be measured? What are the barriers to wide-spread adoption? Which technical questions need to be solved? Is there scope for standardisation? How will the market for such systems evolve?*

1. INTRODUCTION

The task of managing all the information needed to design and construct any major facility is a real challenge, and many believe that more efficient information management is a primary mechanism for the construction industry to increase its productivity (Egan 1998). In the construction IT research literature there are two streams which propose different solutions to the problem of project information management. A solution which builds incrementally on the current documentation practice in the industry, is to enhance this practice through the wide-spread adoption of electronic document management (EDM) systems, applied within companies and in particular across all the participants in projects. Relatively little research has been done related to the technical and implementation aspects of EDM systems in construction. More has been written concerning building product modelling technology and standards implementing this (for a good overview cf. Eastman 1999). In a recent survey made by Betts and Amor (2001) the relative frequencies of research themes were studied in the proceedings of the annual conferences of the CIB Working commission W78 (Information Technology in Construction) over the period 1992-2000. The analysis covered altogether some 500 papers. The graphs presented by Betts and Amor show that there were about 2-3 times as many papers dealing with product modelling, including the STEP and IFC standardisation efforts, as dealing with document management.

The purpose of this paper is to make some observations on our current research knowledge about the introduction of EDM systems in the construction industry. Typical questions addressed in this paper are; *What features should such systems have*? *How much are they used? Are there benefits from use and how should these be measured? What are the barriers to wide-spread adoption? Which technical questions need to be solved? Is there scope for standardisation? How will the market for such systems evolve?* The paper may not provide clear answers to some of these questions, but aims at least to articulate them clearly and thus to help in the definition of an agenda of research needs for the near future.

2. CENTRAL CONCEPTS OF ELECTRONIC DOCUMENT MANAGEMENT

In common language the word *document* usually means an information carrier (usually on paper) containing written or drawn information for a particular purpose. Central to the idea of a document is usually that it can be easily transferred, stored and handled as a unit (Löwnertz 1998). Thus a large part of

the documents handled in today's business world are stored as individual computer files and are treated as units by the operating and email systems.

The current situation in the construction industry is that a mixture of different generation methods is used for managing documents(Björk 2001). Hardly any documents are today produced by hand, but a lot are still transferred by printing them out and sending them to the other parties by mail or couriers, often using copying companies as intermediaries. A slightly more sophisticated method is that documents are both produced digitally and transferred digitally as e-mail attachments. This speeds up the document transfer, but in terms of document management, this hardly offers any improvement over the current situation since finding a document in another person's personal computer may be even more difficult than on his shelves. Retrieving a document may often, as a last resort, require asking a person to deliver it.

The most sophisticated method currently in use is to use document management systems, where the documents are stored centrally on a server and users interact with this central repository through interfaces implemented using standard web browsers.

Electronic document management systems focus on facilitating the management of documents pertinent to particular enterprises, projects and work groups in computer networks. In addition to the basic file management capabilities found in operating systems EDM systems contain enhanced features related to the life-cycle and versioning of particular classes of documents. EDM systems tend to treat the documents they shuffle around as black boxes, just like the post office has little interest is what is inside the envelopes they keep shuffling around, as long as the mail gets to the right recipient in time.

From a document management perspective it is important to distinguish between the primary information within a document and secondary information about the document. This secondary information is often referred to as *meta-data* and it is this which enables humans or document management systems to search for, retrieve and open documents. Meta data was earlier included in the document themselves in the form or cover pages, drawing headers etc. In today's digital environment meta-data is eminently suited for storage in data bases which facilitate searching.

Early document management systems used dedicated networks and user interfaces of their own. It was often very difficult to get the technical infrastructure in place. Since the proliferation of the Internet in the second half of the 1990's almost all EDM systems have migrated to using the general Internet as their physical network, web servers as storage medium and web browsers as the main platform for building user interfaces. Thus there is usually no longer the need for installing any software on the client side and the threshold for joining an EDM system is very low. Some of these systems have been developed in-house, by participant's in the projects themselves, others are offered by third parties as *ASP-services* (ASP = application service provider). An example screendump from one such ASP-service is seen in Figure 1.

Many different names have been used by both service providers and researchers to denote such systems, including Document management system, Project Extranet, Project web, Project Bank, Project Specific Web site, Document Pool, Project information management system, Virtual Project. Some authors give these terms slightly different meanings. A project specific web site (Thorpe, Mead 1998) can, for instance include quite a lot of general information about a building project (i.e. live web cams) in addition to the basic EDM functionality.

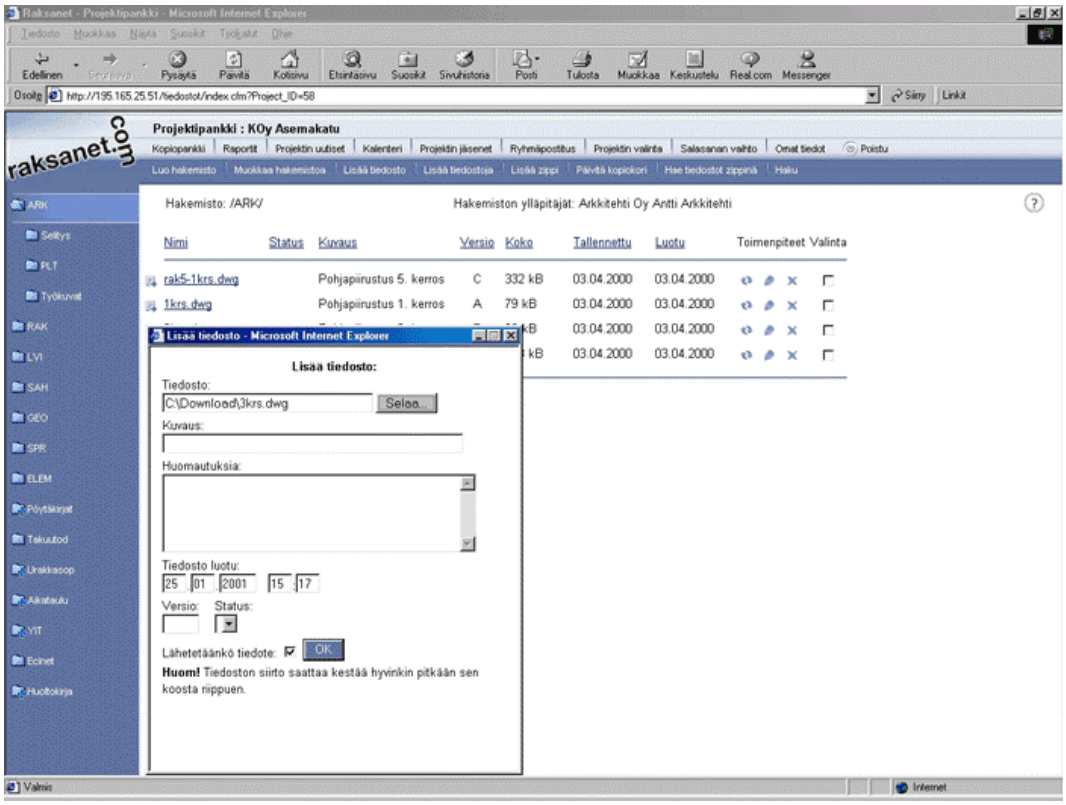

Fig. 1: The Finnish Raksanet (www.raksanet.fi) is an example of the third party Internet based document management service. The screen dump shows how a user is up-loading a document to the server.

3. RESEARCH QUESTIONS AND METHODS

In order to survey the ”landscape” of EDM research in construction, classifications or typologies can prove useful, in a way acting as co-ordinate systems for placing individual research efforts in perspective. In this paper a very simplified typology is applied. It is based on the answers to two fundamental questions; what is the *research question* addressed and what *research method* is used.

3.1. Research questions

In the following a number of central research questions is listed. There are no claims for the list to be comprehensive, and there are interlinkages between the different questions, which haven’t been further resolved. Furthermore some of these questions are typical short term market study questions, others are more long term fundamental research issues. The common denominator is that these are questions which have been asked by researchers reporting on construction EDM in academic refereed journals, conference papers, reports from public research projects etc. For the sake of later references the questions have been numbered:

(Q1) What functionality do systems on the market exhibit

(Q2) How can particular desired technical features be achieved

(Q3) What are the requirements of end users in terms of technical functionality

(Q4) How much and how are systems actually used in practice

(Q5) What are the benefits achieved through the use of EDM systems

(Q6) What are the barriers to the introduction of the systems

(Q7) How do such systems change the way in which practitioners behave and interact

(Q8) How can interoperability between different systems in projects and over time be achieved

(Q9) How can EDM and product modelling co-exist

(Q10) How does the supply, demand and pricing of commercial EDM systems behave

3.2. Research methods

In the following a non-exhaustive typology of research methods or approaches is attempted

(M1) Research using written sources as input

(M2) Conceptual research, for instance involving modelling of data structures or processes

(M3) Broad surveys of industry use, involving paper or web-based questionnaires

(M4) Case studies of use in individual companies or projects, using interview techniques

(M5) Systematic observation of users at their workplaces

(M6) Tracking actual system usage patterns using logfiles of EDM-systems

(M7) Prototyping of small scale systems in laboratory conditions

(M8) Action research, where the researcher has participated in the development of real systems

To take a concrete example the first research in this domain in which the author was involved was carried out in 1991-92 (Björk et Al 1993) and focused on research question Q8 (How can interoperability between different systems in projects and over time be achieved). It tried to provide a potential solution by suggesting how metadata about documents should be structured. The research method used were M2 and M1 (Conceptual research using existing paper documents as an important input).

4. AN OVERVIEW OF CURRENT RESEARCH

The above classification of research questions is in the following used as the outline for a short discussion of recent research literature.

(Q1) What functionality do systems on the market exhibit

Systems which are offered commercially or have been developed in-house contain a vast array of technical features answering true or perceived needs of end users. While most such features can be found in the majority of systems on the market some are more rare. A feature which has proved very important for use on construction sites is a ”viewer” for looking at and redlining CAD-drawings, without having the CAD-software itself installed.

Whereas most systems developers have up-to-date knowledge about the features that their competitors offer, end users contemplating the introduction of systems or the choice of system need checklists and guidelines to help them. For this reason a number of researchers have empirically studied the market offering. This type of research is very useful for practitioners but has a very short life-span, since the features of particular systems is evolving very quickly.

An example of this type of research is the M.SC. thesis of Degerstedt (2000), which was commissioned by a large design consultancy to help in their own strategic planning and involved the study of half-a-dozen systems on the Swedish market at that time. A weakness that this study shares with many other similar studies is that the results are based on system vendors providing answers to questionnaires about the features, rather than testing of the systems by an independent observer. In a study done at the University of Arkansas this problem was tackled by assigning graduate students to test a number of EDM systems (Tinker 2000).

A recent study in this category formed part of the Finnish ProCe project (Luedke et Al 2001). This study was particularly interesting because it compared the features of systems from both Europe and North America and revealed some interesting differences.

(Q2) How could certain features be developed

This type of questions can be answered through prototype work. Typical questions could deal with how the user interface to an EDM system should look like, how versioning of documents should be handled, notification schemes.

Construction EDM presents a very different picture from expert systems or building product modelling, where commercial development was very rare before the last years of the 1990's, but researchers developed numerous prototypes. In EDM research prototypes have been rare but commercial development and deployment has been active. One prototype developed in a research environment but tested in real project work In Hong Kong is reported by Deng et Al (2000).

(Q3) What are the requirements of users in terms of technical functionality.

This is a topic which can be studied using survey and interview techniques. Hartvig (2000) for instance made a systematic study of user requirements in the Danish Construction industry, resulting in concrete guidelines which potential buyers of EDM systems can use as a tool facilitating the choice of systems.

The more features a system contains the more complex it may be to learn, which can create a barrier to usage. Thus the requirements of the end users in the construction industry may not coincide with the spectrum of technical features offered by system vendors. The general lesson coming from this type of research is that the simplicity to learn and use the system is a major factor to be considered. The capability to search documents should also as far as possible resemble current practice, thus relatively simple hierarchical folder structures are popular with end users, despite the more advanced features which can be offered by meta data based search mechanisms.

(Q3) How much and how are systems actually used in practice

This author is not aware of any broad industry wide surveys of only the use of EDM systems in construction. Due to the lack of a single dominant system provider (such as Autodesk for CAD system) it is difficult to find out the overall picture from figures provided by ASP providers, since each of them tend to have only small market shares. There have, however, been a number of general surveys of IT usage in the construction which can give us some indications (Howard et Al 1998), (Rivard 2000). What these surveys show very clearly is that Internet connectivity and the general use of email and the world wide web is already very high in our industry. This is clearly a prerequisite for the use of modern EDM systems. Also there are figures substantiating that already a large share of documents are transferred electronically.

A recent study carried out in Sweden and in a slightly modified form in Finland and Denmark included particular questions about the use of project webs (Samuelsson 2002). The results show in a statistically reliable way that in Sweden almost 50 % of people in the industry worked in companies where project webs had been used in at least one project. Although this isn't as indicative a figure as say the proportion of projects run using EDM systems it at least shows the technology is becoming more common.

On the other hand recently published figures from a study of the IT usage by Australian subcontractors indicates a much lower degree of usage (Ng et al 2001). Although 70 % of the total sample had Internet connectivity and email, the most common usage was for general communication. Only 16 % of respondents indicated email and Internet was used for the exchange of project information.

Preliminary results from an on-going study being carried in the authors research group show that the size of a project is a very important factor in determining whether or not a project web is used (Bäckblom and Björk 2002). In a phone interview with a stratified sample of 100 on-going construction projects it was found that around half of the projects in the biggest size category used a project web, whereas the use was very rare in smaller projects (Figure 2).

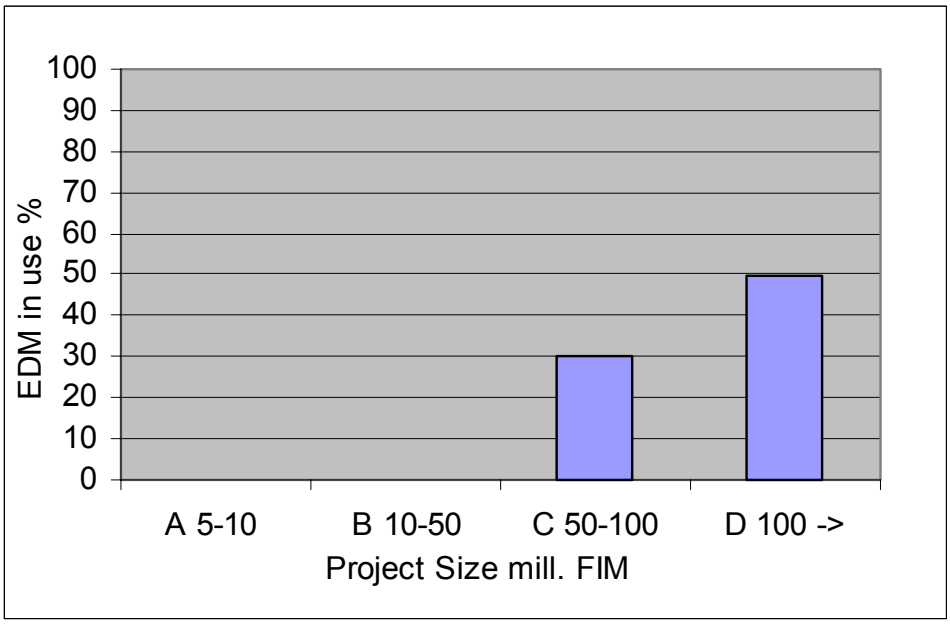

Fig. 2: Use of EDM systems in Finnish Construction Projects in March 2002

(Q4) What are the benefits achieved through the use of EDM systems

The question of how much benefit the construction industry is getting from IT implementation in general has been discussed by several researchers (for a recent exemple cf. Schwegler et al. 2000). Some authors claim to have demonstrated measurable improvements in productivity due to increased IT usage (Thomas 1999). In their critique of Thomas's results Koskela and Kazi on the other hand argue that the use of IT tools as such has had very limited impacts, and that the positive effects are achived more through the changes in working patterns which are induced by the introduction of IT (Koskela and Kazi 2001).

On a more particular level some authors have discussed the benefits which can be achieved through the comprehensive use of EDM systems throughout a design and construction project, stretching into the FM phase. This author for instance is co-author of a prestudy report published in 1994 in which overall savings in the order of 5-10 % of total construction costs were predicted (Löwnertz et al 1995). Proving the realisation of such benefits with empirical data is, however, extremely difficult.

In order to prove any benefits at all some metrics for measuring the benefits should first be defined. The most comprehensive approach has been taken in VTT's ProCe project (Sulankivi et Al 2002) which proposes a metrics based on three major groups of benefits;

- Monetary benefits
- Other quantifiable benefits
- Qualitative benefits

The method which was developed in ProCe has been tested on four construction projects where EDM system had been used (from Finland, Sweden, UK and USA). The projects where middle-sized projects in the order of 25 MEuros. The directly measurable benefits consisted of reduced coping costs, decreased need for travelling to meetings etc. and where for instance in the Finnish case 17300 Euros (representing only 0,1 % of the total project budget). This can be compared to the cost of using the EDM system which was 8500 Euros. Other quantifiable benefits included a reduction of 1700 working days in delivery time of documents. The most important qualitative benefits where the ease of using the electronic site diary which was part of the particular EDM systems used, and the support for distance working.

While the use of precise metrics would be very useful, earlier results from a study carried out by the The Construction Industry Computing Association in the UK showed that design and construction companies rarely use such methods when investing in EDM systems. Furthermore: "In our experience, those few firms that claim to have developed appropriate metrics to measure benefits, such as improved searching and less wasted work on the wrong versions of documents, commonly cite anecdotal evidence gathered from staff interviews" (Wager and Winterkorn 1998, p. 155).

The currently on-going survey in the B-webs project indicates quite clearly that individuals who have used projects webs in projects where the introductions has been unproblematic, would be very reluctant to go back to older ways of managing the documentation (Bäckblom and Björk 2002). This can be seen as indirect evidence that the benefits are greater than the cost or possible inconvenience.

(Q5) What are the barriers to the introduction of the systems

Barriers to the rapid introduction of EDM in construction can be classified int*o technical, behavioural, cost-related, organisational* and *legal*. In case studies of early pilot use of in construction projects from the mid 1990's the technical barriers were often prominent (Höög 1996), (Ahlström 1996). Since construction projects tend to produce a lot of CAD drawings with large file-sizes, the up- and downloading of such files over slow modem or even ISDN-lines was quite problematic. Before Internet and standard connections to it became commonplace setting up the connections could also be quite painstaking. Reasons such as this prompted an early adopter, the Swedish contractor JM-Bygg, to actually enter into partnering agreements with subcontractors who agreed to make the "investment" in time and effort to learn to use the EDM-system that JM had taken into use (Löwnertz et Al 1995).

Over time behavioural barriers, the fact that it is very difficult to get people to change their way of work, have received increasing attention. Already Wedell (1996) in his study of how a large design consultancy should implement EDM noted the tension between "user freedom" and company control. The effective reuse and search for information in an EDM system requires a lot of discipline on the part of the producers of the documents, for instance in filling out meta-data in forms (Ekman 1999). The more standardised the meta data and storage is the easier for users downstream. On the other hand people have always been used to being able to organise their personal archives, including their own hard disks as they please, and now they are forced into a structure which many experience as a straightjacket. Ejbe (1996) points out that the motivation and training of users is essential for successful implementation. O'Brien (2000) has high-lighted the fact that the users of a system in a project cannot be treated as one uniform group, but rather consists of several groups with different attitudes and skills. The problem with an EDM system is that successful use requires that all of these adopt the system at the same time.

(Q6) How does the use of such systems change the way in which practitioners behave and interact

This issue has been studied by a few researchers. Thorpe and Mead (2000) have for instance used social network analysis (a technique commonly used by sociologists and communication researchers) applied to three case projects to study how the introduction of an EDM system has affected the communication pattern between project participants. The sociograms that they developed for the three case projects highlighted the communications patters in a visual form, and demonstrated in two of the three cases the central role that the EDM system acquired (in the third project the EDM system was abandoned after three months of usage). An important conclusion, based on the cases, was that having a technology "champion" – a person who knows the technology and is familiar with its benefits, can be vital to get other participants in the project to adopt the technology.

Also Howard and Petersen (2001) have used social network to study communication patterns in a number of case projects. The approach they took was broader than Thorpe and Mead since they classified communication according to the media used (meetings, post, telephone, fax, email, databases and EDM systems) and they could thus produce figures of the ratio of non-IT to IT communication. In their study they asked project participants to track all their communications over two weeks and fill in the data on forms. They also studied the particular communication stream caused by one construction incident, which lasted for 89 days. They observed that in a crises situation people resorted to more traditional ways of communication; thus telephone, fax and paper mail was relied on to solve the problem.

(Q8) How can interoperability between different EDM systems be achieved

This issue has not been much discussed in the research literature. This is slightly surprising, considering that a lot of the early interest in CAD data exchange (the IGES standard) and product modelling (STEP) started from a recognition of the problems of interoperability between the data representations in different CAD systems. By analogy one could assume that the transfer between different EDM systems would become an important issue over time. In one recent Finnish project, the documentation of a big shopping mall, where one EDM system had been used in the design and construction phase, was transferred to another EDM system for the FM stage. The transfer of the meta data had to be solved with a bilateral ad-hoc solution, and a neutral standard would clearly have been very useful.

This author got engaged in research at VTT in Finland on this issue already in 1991, influenced his earlier engagement in building product modelling. One of the conclusions was that interoperability could be achieved rather easily if the semantics and syntax of the meta data about documents for the construction process could be agreed on (Björk et Al 1993). Later the draft proposal for a conceptual schema was further refined in a international co-operation project (Turk et Al 1994). The work was only done on the conceptual level and the proposal was never tested with document sets from real EDM systems. It was suggested, that for the purpose of exchange between EDM systems, the document meta data could be stored in the format used for product model exchange, i.e. as STEP physical files. More recently technical developments in web technology have provided new possibilities such as XML, and a solution based on this has been developed and tested in the European research project Procure (Watson and Davood 2002).

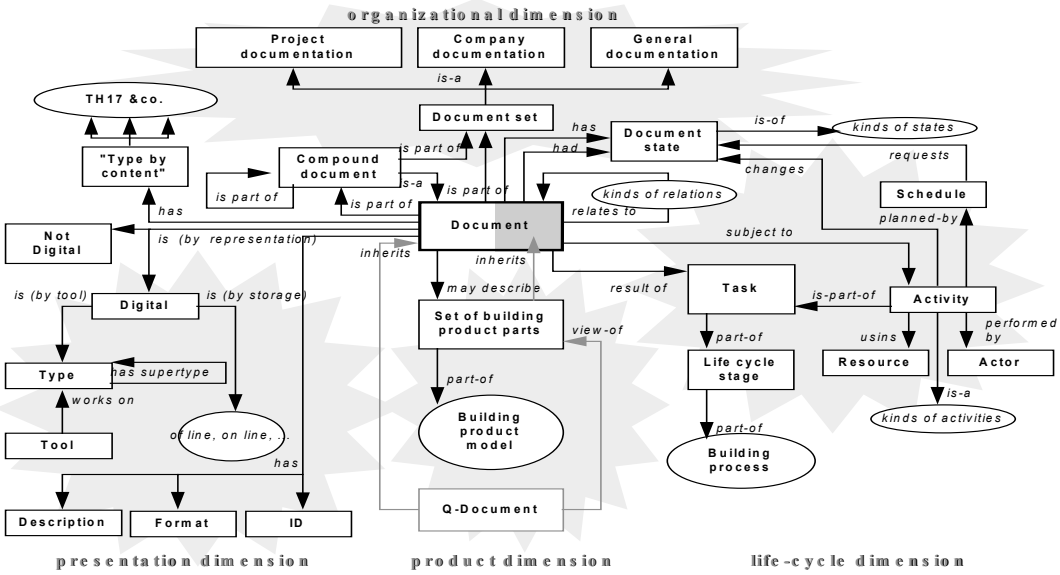

Fig. 3: An international standard for construction document meta data could be very helpful to increase interoperability between commercial systems. The figure shows a proposed conceptual schema for such information (Turk et Al 1994)

(Q9) How can EDM and product modelling co-exist and what techniques are needed to support this

Much has been written in the research literature about building product modelling, since the concept was first introduced in the late 1970's (Eastman 1999). In product data models an object-oriented approach for structuring design data is used. This means that the emphasis is on structuring the information about the product as such, not the documents which describe the product from different viewpoints.

Even if product model based applications become commercially available it is highly unlikely that they could be applied to whole projects and all project participants overnight. Rather product modelling could be applied to certain facets of the overall process and product model data would have to co-exist with more traditional document based information. Some researchers have therefore started to ask if techniques could be developed, which would help in a transfer of information between the two worlds (Rezgui and Debras 1996). Aims like this were in particular part of the ESPRIT project CONDOR (Rezgui and Cooper 1998). One solution is to use the same conceptual schema modelling methods for both document meta data and structure, as well as for the product model information Thus it would be possible to at least migrate data from product model applications to document based systems (doing it the other way would be much more difficult)

(Q10) How does the supply, demand and pricing of commercial EDM systems behave

This is a topic which hasn't been treated in the academic literature, but on which lot's of anecdotal evidence is available through articles in the trade press, presentations by practitioners at exhibitions etc. The recent growth in the supply of commercial EDM services for the construction industry cannot be studied in isolation but should be seen part of the "dot.com" phenomenon or the "new economy". A lot of companies offering ASP solutions for e-commerce and document management for construction were started in the period 1997-1999, to a large extent fuelled by venture capital looking for quick wind-fall profits (CIFE 2000). Many of these companies have since gone bankrupt or merged, and few have managed to start showing the positive cash flows necessary for sustained operations.

The failure of many of these companies is due to the overoptimistic business plans they were based on, both concerning the growth of use of such services and the price levels it would be possible to charge for the services. Price levels have been pressed down by stiff competition caused by the low barriers to enter the market. The growth rate in use in practice has not been exponential but rather linear, due to the high barriers for end users in the industry to adopt these new practices.

The pricing of these services is not very self-evident. Since the service is based on the web and usage can be tracked down to the smallest details there are several options:

- Flat fee for a for a whole project
- Monthly fee for the whole project
- Fee for each participating company
- Fee for each individual who has access rights
- Charging for the amount of web space required document storage
- Charging for each individual transaction (upload, download)
- Sales of the software licence rather than the service
- Financing the service through advertisement
- Bundling the service (for free) with some other service which is the provider's main product

These mechanisms have been used alone or in combinations. The prices charged often have relatively little to do with the marginal costs of producing the service, but rather correspond with the service providers attempt to extract the maximum price from each potential user. These pricing structures have been inspired by pricing schemes for sales of software and mobile telephone services in particular. The technique for running web sites also makes quite complex schemes possible, since actual use can be tracked to a very detailed level. Current market trends at least in Finland and Sweden seem to be towards the simplicity of flat overall fees. Flat overall fees or monthly fees for the whole project are easy to budget for the customers and also to invoice, and do not cause artificial limits to use once the decision has been taken to start using a

system in a project. There have been cases where complex fee structures, where each additional user or upload is charged have caused unnecessary restrains to use the system, which is counterproductive from the viewpoint of efficient document management.
Bundling the document management service with other services is a common strategy. Several systems have been developed by copying companies, who offer the EDM system for free or a very low fee, in order to attract or keep customers for their main business which is the production and delivery of paper copies. It should also be noted that they save costs in their internal production process if customers work via the document management systems which functions as an e-commerce front end for their copying service. Other types of services to tie up with are general construction information services, e-procurement or e-commerce sites.
This is an area where there are increasing returns to scale both on the supply and the demand side (cf. Shapiro and Varian 1999). On the supply side the marginal costs for handling an additional customer is very low, once the software development has been done and costs have been sunk. On the demand side individual companies using systems get benefits from other companies starting to use the technology in general and the systems they use in particular. All in all this creates a situation where there are very strong market forces working towards convergence towards a few market-leading systems.

5. CONCLUSIONS

Based on the above, what do we know about the introduction of EDM systems in construction? Firstly most of the evidence concerning the level of usage or benefits is based on either case studies made by researchers using interview techniques or anecdotal evidence provided by success stories reported in the trade press. Recent evidence from Sweden and Finland indicate a quick growth in the use of project webs, in particular in bigger project, where the use of EDM is likely to become the rule rather than the exception in the near future. The metrics to measure the rather complex causal chain causing the overall cost savings and quality improvements have still only been sketched at, and reliable measurements with large enough data sets to isolate the effects of the learning curve or external factors are missing. Also the possibilities offered by the technology for studying the detailed log files of how system are used have not been utilised for research purposes.

What is clear from the many reported case studies is that technical problems or the cost of using systems are no longer barriers to wide-spread adoption. Rather the organisational issues surrounding the use (who is in control) as well as the psychology involved in getting all participants in projects to accept using new technology are now in focus. A major concern for many projects considering using the technology is the long-term reliability of third party services. This is a very volatile market where the turnover of service providers has been very fast.

On the technical side the systems offered by vendors tend to converge in the features they offer, due to the highly competitive market. Development costs for a basic systems are not exceedingly high and thus the barriers to entry are low. This situation combined with very low marginal cost of taking on new customers has led to prices of EDM services going down very quickly.

The role of standardized meta data as possible integrator between different systems has been recognised by some researchers and also by international standardisation bodies (IEC 2001), but has understandably not been a priority development item for system vendors. One example of a standard proposal is included in the project web guidelines issued by IBB, the Danish Construction Industry IT users association (IBB 1999).

All in all the situation of rapid uptake of the technology offers excellent opportunities for empirical research which could help in solving some of the research questions outlined earlier in this paper.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Ahlström, Joakim 1996. Studie av datorstödd ärendehantering i byggprocessen, (in Swedish, Study of computer-based workflow management in the construction process), M.Sc. thesis 304, Division of Construction Management and Economics, Royal Institute of Construction, Stockholm

Betts, M. and Amor, R., 2001. Information Technology for Construction : Recent work and Future Directions, Paper presented at the CIB world conference, Wellington, New Zealand, 2001

Björk, Bo-Christer, 2001. Document management - a key technology for the construction industry, In: Information and Communications Technology (ICT) in the Practice of Building and Civil Engineering, proceedings of the 2nd worldwide ECCE Symposium, Espoo, Finland 6-8.6.2001, Association of Finnish Civil Engineers, Helsinki, Finland, pp. 35-43

Björk, Bo-Christer; Huovila, Pekka; Hult, Sven 1993. Integrated Construction Project Document Management (ICPDM), In Behesti, M.; Zreik, K. edts. *Advanced Technologies - architecture - planning - civil engineering*, proceedings of the EuropIA'93 conference, Delft, 21-24.6.1993, Elsevier, Amsterdam, pp. 135-146

Bäckblom, Magnus; Björk, Bo-Christer 2002. Current use of EDM systems in the Finnish Construction Industry
Accepted paper, the European Conference on Product and Process Modelling in Construction, Porto Roz, Slovenia, 9-11.9.2002

CIFE, 2000. E-Commerce and E-business in Design and Construction: Getting Started and Staying in Business
Conference organised by the Center for Integrated Facilities Engineering, Stanford University, 8.4.2000, http://www.stanford.edu/group/CIFE/ecommerce.summit.html

Degerstedt, A., 2000. Inventering och utvärdering av elektroniska dokumenthanteringssystem i byggprocessen, M. Sc. Thesis, No. 386, Dept. of Construction Management and Organisation, Royal Institute of Technology, Stockholm, Sweden, 2000,
http://www.indek.kth.se/bit/thesis/386.htm

Deng, Z..M. ; Li, H.; Tam, C.M..; Shen, Q.P..; Love, P.E.D. 2000. An Application of the Internet-based Project Management System, Automation in Construction Vol. 10(2000), pp. 239-246

Eastman, C. M. 1999. Building Product Models – Computer Environments Supporting Design and Construction, CRC Press, Boca Raton, Florida

Egan, J. 1998. Rethinking Construction, Report of the Construction Task Force on theScope for Improving the Quality and Efficiency of the UK Construction Industry, Department of Environment, London

Ejbe, Mattias 1996. Erfarenheter från datorsamordning i större byggproject, (in Swedish, Experiences of IT-coordination in larger construction projects), M.Sc. thesis 304, Division of Construction Management and Economics, Royal Institute of Construction, Stockholm

Ekman, Tom. 1999. Dokumentpooler – Elektronisk dokumenthantering i byggprojekt. Byggandets Organisation och Ekonomi, KTH, Stockholm., http://www.indek.kth.se/bit/svpub/tom/1999/1/tom1.htm

Hartvig, Susanne 2000. Vejledning i evaluering af projektweb (Guidelines for the evaluation of project webs), Technical report, BYG.DTU R-002, Department of Civil, Engineering, Technical University of Denmark

Howard, Rob; Petersen, Ernst 2001. Monitoring Communications in Partnering Projects, Electronic Journal of Information Technology in Construction *(ITcon)*, Vol 6(2001), pp. 1-16 http://www.itcon.org/2001/1/

Howard, R., Kiviniemi, A., Samuelsson, O. 1998. Surveys of IT in the Construction Industry and Experience of the IT Barometer in Scandinavia, *Electronic Journal of Information Technology in Construction (ITcon)* Vol 3, pp. 45-56, http://itcon.org/1998/4/

Höög, Peter 1996. Datorstödd dokumenthantering i ett större byggproject, (In Swedish, Computer-Based Document Management at a Large Construction Site), M.Sc. thesis 300, Division of Construction Management and Economics, Royal Institute of Construction, Stockholm

IBB 1999. Dataudveksling via Project Web, Publication 7, IBB, Teknologisk Institut, Taastrup, Denmark.

IEC 2001. IEC 82045-2 Document Management, Part 2: Reference collection of metadata and reference models,
Committee draft, 2001-04-30, International Electrotechnical Commission, Geneva

Koskela, Lauri, Kazi, Sami 2001. Information Technology in Construction: How to realise the benefits. Working paper, Technical Research Centre of Finland.

Luedke, Mary, Lakka, Antti, and Sulankivi, Kristiina, 2001. Existing Features And Attributes In The Concurrent Engineering Environment. In Proceedings, 2nd Nordic Conference on Construction Economics and Organisation. Chalmers, Sweden.

Löwnertz, K., 1998. Change and Exchange – Electonic Document Management in Building Design, Licentiate Thesis, Dept. of Construction Management and Organisation, Royal Institute of Technology, Stockholm, Sweden.
http://www.indek.kth.se/bit/doc_thesis/kurt_lic/abstract.htm

Löwnertz, K., Johansson, C., Lindgren, N., Björk, B.-C., 1995. Datorstödd hantering av dokument i bygg- och förvaltningsprocessen. Rapport, Byggandets informationsteknologi, Kungl tekniska högskolan, och CITB, Chalmers tekniska högskola, Stockholm,

Ng, S. T.; Chen, S. E.; McGeorge, D.; Lam, K.-L.; Evans, S. 2001. Current State of IT usage by Australian Subcontractors
Construction Innovation, Vol 1., Nr. 1, March 2001, pp. 3- 14

O'Brien, William 2000. Implementation Issues in Project Web-sites: A Practitioner's Viewpoint, preprint version of a paper published in ASCE Journal of Management In Engineering, May 2000, Vol 16 (3), pp. 34-39

Sulankivi, K., Lakka, A., Luedke, M. Project management in the concurrent engineering environment. VTT Publications. Technical Research Centre of Finland, 2002,
http://www.vtt.fi/rte/cmp/projects/proce/indexe.html

Tinker, Audrey, 2000. Comparative Analysis of Nine Major Project Management Systems for the Construction Industry. Working paper, University of Arkansas at Litte Rock.

Thomas, Stephen R. 1999. Impacts of Design/Information Technology on Project Outcomes, Report NIST GCR 99-786, National Institut of Standards and Technology, Gaithersburg, Md., USA

Thorpe, Tony; Mead,Stephen 2001. Project-Specific Web Sites: Friend or Foe? Journal of Construction Engineering and Management, October, Vol 127(2001), Issue 5 pp. 406-413

Rezgui, Yacine; Cooper, Grahame 1998. A Proposed Open Infrastructure for Construction Project Document Sharing
Electronic Journal of Information Technology in Construction, Vol 3. (1998), pp. 11-24
http://www.itcon.org/1998/2/

Rezgui, Yacine; Debras, Philippe 1996. An Integrated Approach for a Model Based Document Production and Management
Electronic Journal of Information Technology in Construction, Vol 1. (1996), pp. 1-21
http://www.itcon.org/1996/1/

Rivard, H. 2000. A Survey on the Impact of Information Technology in the Canadian Architecture, Engineering and Construction Industry, Electronic Journal of Information Technology in Construction (ITcon) Vol 5(2000), pp. 37-56, http://www.itcon.org/2000/3/

Samuelsson, Olle 2001. IT-Barometern 2000 - En undersökning om IT-användning i bygg- och fastighetsbranschen, Rapport, IT Bygg och Fastighet 2002, Stockholm, Sverige

Shapiro, Carl, Varian, Hal 1999. Information Rules – a Strategic Guide to the New Network Economy, Harvard Business School Press, Boston, Mass., USA

Schwegler, Benedict; Fischer, Martin; O'Connell, Michael; Hänninen, Reijo; Laitinen, Jarmo 2001. Near-, Medium-, & Long-Term Benefits of Information Technology in Construction, CIFE Working Paper No 65, July 2001, Center for Integrated Facility Engineering, Stanford University

Turk, Ziga; Björk, Bo-Christer; Johansson, Curt; Svensson, Kjell, 1994. Document Management Systems as an Essential Step Towards CIC, Preproceedings of the CIB W78 workshop on Computer Integrated construction, Technical Research Centre of Finland, Espoo, Finland, 22-24.8.1994, 12 p.

Wager, D.; Winterkorn, E. 1998. Document Management for Construction, Report, Construction Industry Computing Association, Cambridge, UK

Watson, A.; Davoodi, M. 2002. Transferring Project Documents and Associated Metadata Between Company Document Management Systems and Project Extranets, Accepted for publication, eSM@RT conference, Salford, UK, November 2002

Wedell, Erik 1996. Computer Aided Document Management – A system specification supporting the management of internal project data in a design consultancy organisation, M.Sc. thesis 302, Division of Construction Management and Economics, Royal Institute of Construction, Stockholm