Downstream of Design: Web-based facility operations documents

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Abstract: Internet technologies provide opportunities for improving the delivery of facility information to building owners and operators. Discussions with facility operators have led to identification of problems in current practices of delivering facility information using as-built drawings. A Web-based software prototype illustrates how facility information can be automatically structured into documents that support specific facility operations tasks.

1. INTRODUCTION

Beyond the design phase, and even beyond the construction phase, the documentation of a building lives on in support of operations and management. In speaking with building owners, we have uncovered a widespread concern that building documentation as delivered by designers or constructors is inadequate for supporting building operation. There is a need for information to persist throughout the facility life cycle and for project participants to be aware of the downstream uses of information. Facility operators use so called “as-built drawings” in conjunction with test and balance reports, maintenance manuals and many other kinds of information. There is rarely a coherent and integrated strategy to co-ordinate, format and cross-reference the information provided from many sources. To better understand the shortcomings of contemporary practices in delivering building documentation, our research has examined building documentation from the viewpoint of owners and operators. We have focused upon emerging Internet and intranet technologies to develop guidance toward new practices that are likely to reduce the difficulties perceived by building operators.

Our investigations have led us to re-conceive as-built drawings as *just-in-time operations documents*. This new concept for organising facility information exploits Web-based tools to collect, structure and deliver facility information to the point of use. Using automated scripts running on Web servers, generic repositories of electronic data can be reused and linked to support typical work tasks. Although our research has not yet produced a fielded implementation, our working prototype suffices as a proof-of-concept and provides us with confidence in our recommendations for the delivery of facility documentation.

This paper presents the results of several years of research that remains in progress. We will introduce our research questions, the scope of our explorations and our research methods. We will then describe the changing environment of the AEC industry as the background to our research. Next, we will enumerate problems with facility documentation in supporting operations. A short section then introduces the collection of technologies that we have found to be useful. We will then describe the working prototype that we have constructed to illustrate a vision of future information systems to support facility operations. We recommend formats and practices that can be followed by building owners and consultants to facilitate delivery of facility information into Web-based information systems. Finally, we will discuss future research and summarise our conclusions.

1.1 Research questions

The overall question behind our research has been "Can building information be supplied by the AEC team in a more effective way so that it will better meet the needs of facility management work processes?" In turn, this question has suggested three other questions that help to frame this research:

1. What is the structure and content of information that is currently delivered by the AEC team?
2. What is the structure and content of information that is needed for facility management?
3. What is necessary to close the gap between what is delivered and what is needed and can recent advances in information technology create new opportunities to redefine the nature of facility organisations?

At this point, we have conducted several research projects that have focused on these three questions. These studies have produced an improved understanding of the processes that use facility documentation and the emerging information technologies that can contribute to new forms of facility documentation.

1.2 Research methods

The research reported in this paper investigates the information interfaces among building designers, building contractors, and the facilities and services department of a large insurance and financial services company, USAA. In particular, we have focussed upon the needs of the building operators who manage and maintain building services on a routine basis, perform repairs, and make changes to the systems to accommodate remodelling.

We have undertaken several activities to assure that our research can be of broad interest and is influenced by a broad range of input. Site visits with numerous facility management organisations have enabled us to catalogue a range of

technology solutions that could potentially be useful in solving these specific problems or, potentially, be useful in proposing changes within the facility management organisation. Discussions with industry groups and several government task groups have acquainted us with related initiatives. Contact with software vendors has enabled us to understand the current state of art.

Concurrently with discussions with our sponsor and other facility management organisations, we investigated Internet technology from the point of view of implementing a corporate intranet to distribute facility operations information. We undertook quick exercises with emerging Web-based tools and constructed software prototypes. Our purpose in these explorations has not been to create a new software product, but instead to create an image of a future facility operations information support system. The prototype enables us to define the requirements for structuring and formatting facility information that can be delivered by design and construction consultants now that can be easily incorporated into the future system.

2. BACKGROUND

This project has been conducted upon a backdrop of an Architecture/Engineering/Construction (AEC) industry that is undergoing tectonic changes. Architects' clients are becoming more sophisticated. They demand different services and a higher degree of understanding of their business practices. Simultaneously, the World Wide Web (the Web) has provided a culture for start-up companies that are providing new services that address current shortcomings in practices in the AEC industry. Existing and new industry groups have recognised that information exchange is a key to improving performance in the AEC industry and are championing different approaches that facilitate this exchange.

2.1 Changes to the professions

Architecture has never been a very homogenous industry. However, a recent industry survey suggests that the profession may be growing even more diverse in response to market pressures. For example, there is continuing evidence from the most recent AIA Survey (AIA 1997) that large architecture firms, particularly those with 50 or more employees, are increasing their share of the market. At the time of this survey, less than 9% of the largest firms accounted for over 60% of total industry net billings—an all-time high. These firms are often multi-disciplinary and generally service clients of large organisations who design, build and operate large, expensive and complex facilities. These clients demand a full range of services to meet their facility needs and are changing the nature of architectural practice from a project focussed process to a client focussed process. As Gutman has stated (1998, 50) the big organisation clients "set the standards according to which architecture is practiced".

These same large clients are turning increasingly toward enterprise resource planning (ERP) systems such as SAP and Oracle to help them manage the large amounts of information associated with operating their corporations. These organisations have learned the value of information and are continually mining data to leverage this information in an effort to become more efficient. For many of these large organisations, information technology "… is integral to processes

internal to the firm, to product design, to delivery of services, and to inter-organisational relations" (Allen and Scott Morton, 1994, vi). As a result, information technology is becoming increasingly important as a strategic business tool. Since CEOs and CIOs are seeking to integrate enterprise-wide information, they are also requiring data pertaining to the design, planning and operation of their facilities.

These changes in the services demanded by building owners require architects to have a greater understanding of the role of information in the design, construction and operation of buildings. Such a focus on information is likely to alter substantially the traditional ways of providing architectural services and, perhaps more important, the methods and procedures by which architectural information is supplied. If information is becoming increasingly important to the practice of architecture and if large, corporate clients are “setting the standards” for the practice of architecture, then it follows that architects must better understand information needs throughout a building’s life-cycle.

2.2 Opportunities arising from the Web

The World Wide Web is dramatically changing many aspects of professional practice in the AEC industry, particularly in communication and information storage and retrieval. Initial use of the Web by architects included precedent or product research, and firm home pages as a branch of marketing (Padjen 1997). The Web is now being used more actively to improve communications and information management. Some architects are establishing project “extranets” where all project design and construction information can be collected and then viewed by project participants (Mays 1998). At the completion of the project, the repositories can be written to a CD-ROM and delivered to the owner for use in facility management. However, current use of project Web sites does not clearly anticipate facility operations application of the information. The emphasis has been upon supporting the communication among design and construction team members.

Future design support systems may provide more sophisticated functions. Computer-Aided Design (CAD) software is becoming “internet-enabled” (Regli 1997). Drawings can be viewed using a Web browser and links to other documents embedded. Virtual Reality Modeling Language (VRML) 3D models can be distributed across the Web and then explored interactively by participants on a project team. Java applications can perform design evaluation calculations. Design analysis services could be distributed on the Web. Internet-based multimedia communication software, such as NetMeeting, can support design discussions that include graphic sketching and even multi-person interactive CAD sessions (Al-Qawasmi et al. 1999).

Taken together, these new technologies provide extensive opportunities to re-engineer design, construction and facility management information to achieve greater integration and to streamline operations processes.

2.3 Industry initiatives

While Web-based tools have been adopted quickly, other advanced computer methods, although promising and potentially very effective, have taken longer to reach maturity. Web-based tools are relatively generic in that they address

distributing, viewing and recording information without placing many demands upon semantics behind the information. Several groups are directly addressing semantics of building information to facilitate information exchange and sharing.

At the simplest level, building information can be shared in common formats, such as building geometry that is represented in IGES or DXF formats. By using a convention for dividing information into layers, such as the AIA CAD Layer Guidelines, a degree of non-graphic information can also be shared (Schley, et al. 1997).

Product modelling under the STEP umbrella aims to define the semantics and syntax of information to enable its unambiguous exchange among computer systems (Watson 1995). Various computer systems may be used by many engineering disciplines throughout the product lifecycle and across geographic and time constraints. In the AEC domain, COMBINE and ICON are two research projects that have developed generic, central models of buildings that may be shared among many users (Augenbroe 1995, Cooper and Brandon 1995).

The Construction Specifications Institute is addressing information integration for the AEC industry that builds from its widely accepted CSI format and Uniformat systems. They have recently published the Uniform Drawing System that provides guidelines for the layout of drawings and the use of symbols and noting on those drawings (CSI 1997). Based upon an industry-wide study, they plan to produce a classification system, a thesaurus of terms used in the U.S. construction industry, and ultimately an "Integrated Information model" that addresses the life cycle of facilities.

In addition, several U.S. government agencies are addressing the creation of standards for facility management information. The Tri-Services CADD/GIS Technology Center is developing standards for the U.S. Armed Forces bases and buildings. A group working out of the National Institute of Health and the National Institute for Building Sciences is examining the use of SGML as a standard for representing building information. A Document Type Definition (DTD) is in development that will define tags and their semantics that can be used to add structure to text files.

The International Alliance for Interoperability (IAI) is a consortium of software vendors, design and construction firms, researchers and government agencies that posits a standard for object definitions for the AEC industry. The concept is to establish a framework by which vendors can produce compliant software that will work effectively with compliant software from other vendors.

At a still more sophisticated level, the concept of individual applications dissolves as software distributed across a network can transparently pass information and obtain processed results. Perhaps by creating component-oriented interfaces or standards using Java, a vision of distributed design or modular CAD can be implemented (Eastman, Chase and Assal 1993, Zamanian 1995).

Among these initiatives there is a predominance of attention to supporting design and construction rather than facility management. The emphasis has also been upon directly addressing the data standards rather than envisioning the software that will make use of those standards. Our research is distinctive in our emphasis upon facility operations and our development of a software prototype of a future information system that uses Web-based technologies.

3. PROBLEMS WITH CURRENT FACILITY DOCUMENTATION

We elected to pursue a problem-driven methodology for this research project. This approach allowed us to ground our research in specific issues that would be of relevance to the AEC-FM community. We conducted our investigations by combining widely targeted surveys, short interviews with a variety of facility management organisations, and an in-depth series of discussions with facility managers and operators in our sponsoring organisation.

3.1 Identification of Industry-Wide Problems

In our 1997 survey of Fortune 500 facilities organisations (Johnson and Clayton 1997), we found a number of problems that were inhibiting the implementation of information technology solutions and that there appeared to be some differences between service and manufacturing companies. Reported problems included evaluating the costs and benefits of information technology, keeping information up-to-date, customising software, educating staff in new technologies, and acquiring data about a facility for inclusion in information systems. Clearly many facility management organisations are experiencing significant problems as they sought to make better use of information technology to improve their practices.

Other researchers have documented perceived problems with the documents that are commonly produced by designers and constructors when they are used to support facility documentation. A survey of U.S. Army facility managers reached a conclusion that as-built drawings are poorly structured for supporting maintenance and operations and may be missing important information (Liu et al. 1994). This study concluded that more attention to design standards and criteria, warranty information, maintenance records, condition of equipment and facilities, and utility information is warranted.

Clearly, problems with the delivery of facility information to building owners are widespread. However, there are diverse concerns and factors that probably vary among organisations. Our subsequent work with USAA allowed us to focus on specific problems that were of interest to one specific company.

3.2 Identification of Problems at USAA

Our approach with USAA was to identify problems through a variety of mechanisms, including focus-group sessions, interviews, and surveys of operations personnel. From this investigation we identified a number of problems that can be categorised into three groups:

1. Problems with content
   - Operational sequences for running the facility are missing.
   - The original design intent is missing.
   - Documentation of underground services may be missing or inaccurate.
   - Training documents are missing or have proven ineffective.
   - Equipment tags are do not conform to internal standards or are not used consistently. Labels on drawings may not match those on equipment or may use different conventions from labels on other drawings.

2. Problems with format and delivery
   - Information for a specific project is distributed across a wide variety of sources. It is difficult to know what source to consult.
   - Drawings are often too complicated for facility management tasks and contain information that is superfluous.
   - Information is not integrated across functional building systems. For example, mechanical equipment should be co-ordinated with electrical--it is important to know what circuit feeds a particular piece of equipment.
   - Provision of information at point of use is often a problem. For example, cables need to be labeled at both ends. Electrical panels need to be properly labeled and the labels coordinated with plans. Labels on panels may be too general, such as "Lights," or may be too specific, such as "Lennox 3245A."
3. Problems with information collection and up-date
   - Historical information is in paper format or obsolete digital formats that cannot easily be integrated into current information systems.
   - Facility information is difficult and costly to keep it up-to-date.

Further discussions with USAA revealed categories of facility information that are strong candidates for improved documentation (Clayton et al. 1998). Schedules, such as electrical breaker panel schedules, valve tag schedules, door hardware schedules, and lock set schedules were deemed very important yet with low satisfaction. Mechanical design rationale was also frequently mentioned as a kind of facility information that could be crucial to effective operation but was rarely captured and stored effectively.

Design and construction consultants who work with USAA revealed other issues. Each consultant has an independent information delivery approach. While consultants are dedicated to providing satisfactory service, they are also reluctant to change their practices to meet the needs of a single client. A building owner must avoid draconian solutions and requirements that consultants can not or will not meet.

3.3 Problem Summary

Our discussions provide pictures of facility information across processes in design, construction and operation. Designers and constructors tend to create and deliver information to owners in format and with structure that is appropriate to their internal processes. Designers and constructors often have little awareness of the downstream uses of the information. Facility managers and operators put the information to a variety of uses during facility operation and need to locate, retrieve, and filter information rapidly to support a variety of tasks. Maintenance and up-date of the information is a crucial part of an effective facility operations information system.

Three ways of organising facility information appeared important in the overall process. For construction, information is conventionally organised by disciplines and trades such as by the CSI format and the Uniform Drawing System. For training and troubleshooting during facility operation, information needs to be organised by functional system that may span across disciplines and trades. For example, altering a fan coil unit may require information from HVAC drawings, electrical drawings, test and balance reports, control systems and other sources. The CSI UNIFORMAT classification is a precedent for this view. Finally, information also needs to be provided to support specific work tasks, control a sequence of tasks and co-ordinate

multiple personnel. Up-dating facility information is a crucial step in many operations work tasks.

Careful attention must be paid to incorporating information into computer systems. A large amount of "data scrubbing" such as conversion of paper drawings to CAD or conversion of CAD drawings to databases could place undue burdens upon consultants or internal resources.

We summarised these problems in prototypical use scenarios. Potential scenarios could be identified by focusing on recurring and routine problems, critical problems, or stand-out headaches. Since critical problems appeared to be handled well by USAA, we decided to focus on recurring and routine problems. We have chosen the following scenarios to guide our implementation of a prototype:

1. Adapting HVAC systems to remodelled offices and expansion projects.
2. Substituting and replacing filters in HVAC system equipment and ducts.
3. Training personnel in equipment shut-down procedures.
4. Trouble-shooting and fixing electrical circuit overloads.

Our next step was to gain an understanding of appropriate information technology in preparation to build a prototype to address the scenarios. We focused upon Internet and intranet technology because it provides hypertext and hypermedia, it is platform independent, and it is relatively low cost.

4. INTRANET TOOLS FOR FACILITY DOCUMENTATION

Our initial effort in attempting to identify future information systems for facility management was to survey Web-based development tools that are entering the marketplace. We then obtained the tools whenever possible and performed experiments with them to develop a feel for their utility and ease of use. This section describes the tools and techniques that most contributed to our development of a prototype:

- **Web browsers and HTML** The fundamental technology in our explorations is the use of Web browsers and HTML to implement an "intranet". These are established, proven and popular technologies for publishing information across a network.
- **Dynamic HTML.** This is not really a technology but is a loose collection of technologies. It includes Java, ECMA Script, the Document Object Model (DOM), Cascading Style Sheets (CSS) and other accepted or proposed formats that enable the appearance of HTML files to be adjusted on the fly. The Document Object Model is a representation of the structural parts of an HTML document or XML document as a "part-of" or container hierarchy. It enables programming additions to HTML to access attributes and formatting.
- **Relational Database Management Systems.** RDBMS systems, such as Microsoft SQL Server and Oracle, are a fundamental repository for information that is structured into fields and records. Open Database Connectivity (ODBC) is a widely supported standard for performing queries on many brands of RDBMSs.
- **Active Server Pages (ASP).** Our explorations relies upon generating HTML pages that are then sent to Web browsers. Microsoft's technology for doing that is Active Server Pages. With ASP, one can insert HTML fragments,

perform database queries, and process the values in user input fields to generate HTML code on-the-fly.

- **Drawing Web Format (DWF)**. Autodesk has continued to refine the DWF format for use on the Web and in intranets. DWF files can have multiple named views, and layers that can be toggled on and off as well as embedded links. The settings can be controlled via Java Script and parameters in the HTML code.
- **XML**. This format is likely to replace HTML for intranet applications. It provides enriched structure that enables machine processing of documents to support multiple uses. Documents can be marked up for content and semantics by using a Document Type Definition (DTD) that defines custom tags. A master document can include sub-documents to promote sharing of boilerplate among several documents. Style sheets may be stored in separate files and shared among multiple documents.
- **Web-based redlining.** A number of tools are becoming available that allow simplified editing of a CAD file to support mark-ups, note errors, and indicate changes. Redlining tools can operate in conjunction with a browser and CAD drawings to enable mark-ups to be managed via the Web.

5. JUST-IN-TIME FACILITY DOCUMENTS

These investigations of Web technologies applied to problems in facility documentation have led us to a concept of just-in-time (JIT) facility operation documents. We have developed a prototype JIT operations document information system to prove the feasibility and potential usefulness of the concept.

5.1 The JIT quality

The acronym of JIT originated in the manufacturing field. The idea is to pull necessary materials for production from a station downstream when needed instead of constantly pushing materials to the next process upstream (Karmarkar 1989, Duncan 1988).

We have applied the JIT concept to facility documentation. Our approach is to store facility information in relatively generic repositories and then collect, format, and filter the information for distribution only when it is needed to support a particular task. Instead of a traditional approach of pushing facility information to the operations personnel in the form of three-ring binders and stacks of drawings, our concept is that operations personnel pull the information from digital repositories using Web tools only as needed.

5.2 Prototype implementation

We have implemented a prototype JIT operations document system. This prototype system generates documents based on requirements of the specific task. We have demonstrated the prototype to field facility operators. Our preliminary conclusion is that it successfully generates facility operations documents, providing information necessary for specific operational tasks.

Our prototype delivers concise and complete information that is focused on specific operations tasks. The following implementation concepts are embodied in the prototype: 1) Generic repositories, 2) Link farm, 3) Task-centric document generation, and 4) Automated workflow management.

5.2.1 Generic repository of facility information:

Existing and emerging standards for electronic documents provide a strong starting point for a JIT operations document system. Our prototype system stores facility information in data repositories that are relatively generic and unstructured. These repositories conform to current practices and proposed standards, such as the Uniform Drawing System, the AIA CAD Layer Guidelines, and the Tri-Services standards. They also apply a principle of using information in "natural" formats. For example, although architects often deliver schedules as drawings, they are more naturally represented as tables that should be delivered as spreadsheets or databases. Table 1 describes our recommendations for delivering facility information and incorporating it into the generic repositories.

Table 1. Generic repository formats and information structure

Types of documents	**Required formats and standardisation**
Drawings	CAD format and web-enabled format (e.g., DWG or DWF) Sheet organisation standard (e.g., Uniform Drawing System) Label names and equipment tags as provided by owner Layer standard (e.g. AIA CAD Layer Guidelines) Embedded links on all scheduled items (e.g. Mechanical equipment, electrical equipment, control devices) Symbology provided by owner, as suggested by Tri-Services
Product and performance data, such as schedules and test and balance reports	Spreadsheets or databases, with templates and fields provided by owner (Uniform Drawing System provides recommendations)
Equipment operation and maintenance manuals	HTML format and either Web or CD-ROM delivery PDF format if HTML format is unavailable Optical scanning if only paper-based documents are available

Other kinds of information are needed in facility operations but are not currently delivered in any format. Table 2 describes our recommendations for formats and structure for information that is not currently delivered to building owners. These recommendations will require further research and refinement to establish effective standards that can be widely adopted.

Table 2. Recommendations for facility information for which there are no clear standards

Types of documents	**Required formats and standardisation**
Design intents	XML document type definitions and authoring tools
Work processes	Documentation of processes through IDEF0, pseudo code or Web scripts

5.2.2 Link farm

A "link farm" is a database that stores hyperlinks, providing for improved management of hyperlinks. We have derived our link farm concept from a link management technique described in an XML reference (Light 1997). The link farm has several purposes:

- Defer assignment of physical location of files that are targets in links that are embedded in other documents;
- Facilitate global adjustment of targets;
- Implement bi-directional links and one-to-many links;
- Classify links by information content; and
- Provide for auditing of traversals of links.

Our implementation uses Microsoft Access databases and Active Server Pages (ASP) to insert a level of indirection upon the hyperlinks in our JIT facility operations system. Images of the tables are illustrated in Figure 1. The database contains records for each hyperlink that store the physical location of files and markers for each end of the link and classify the link by information content. Links embedded into drawings and HTML documents point to ASP documents that perform queries on the link farm to resolve links. The queries can initiate relatively simple traversals or complex searches of information. They may return compound documents that combine information from multiple sources.

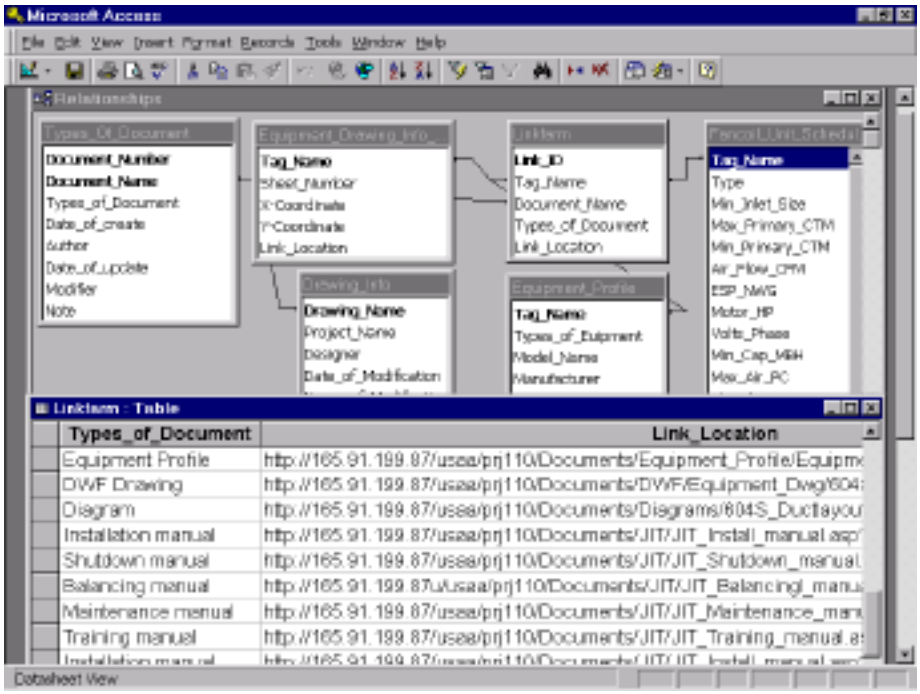

Figure 1. Link farm database tables used in the prototype

Fortuitously, the link farm also provides a way to audit the use of the information system. When invoked, the ASP scripts create new records in an audit

database that records the person requesting information, the time, and the source link for the query. From these audit records, the personnel in charge of maintaining the facility information system can detect patterns of use and anticipate important information to include.

The link farm also easily accommodates discipline-oriented, hierarchical models of the facility. Figure 2 illustrates such a view in our prototype system.

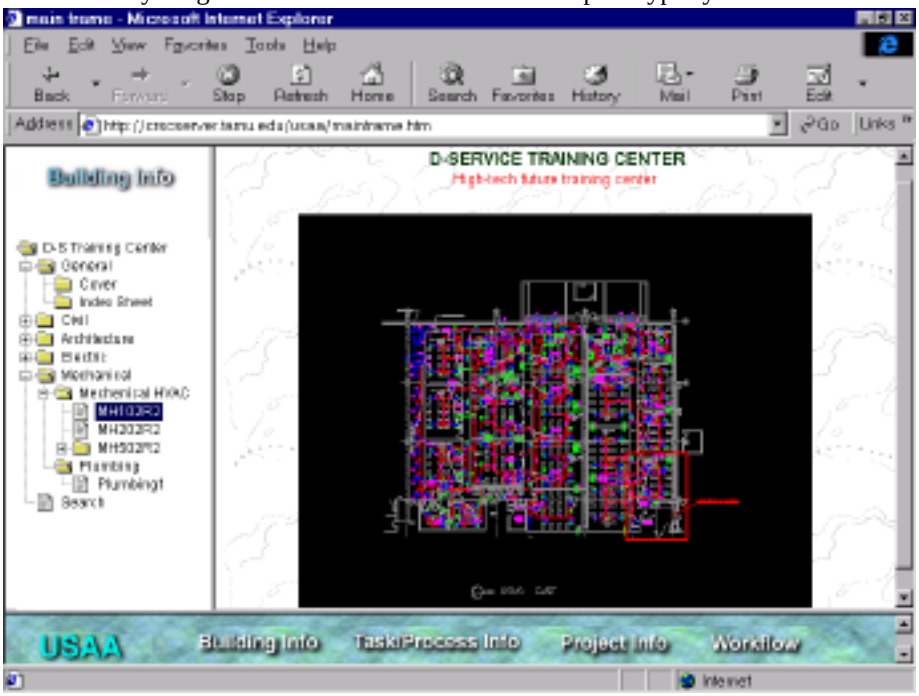

Figure 2. Functional system view of facility information

5.2.3 Task-centric document generator

The documents provided to a user of the system are generated on the fly using ASP scripts. The scripts record knowledge of what information is needed to perform a facility operations task, such as one of the scenarios described in a previous section. In use, the JIT operations document system allows the user to specify parts of a facility and the task. It then selects a template for that task and inserts information specific to the particular work order. For example, installing a fan coil unit is a relatively routine task. The information needed for that task and the process of performing that task is stored in a template. When a person requests information for changing a specific fan coil unit, the software collects the specific drawings, maintenance schedules, and shut-down procedures and other documents necessary for the specific task.

In our prototype, the task-centric templates have been created with Active Server Pages in conjunction with Java Script and VB Script. They generate HTML documents on the fly by querying the link farm for the needed link targets. A script retrieves records from a database, drawing files, diagrams, images, text and many

other kinds of formats of data and generates a concise document in a predefined format. Figure 3 illustrates a JIT operations document generated to provide training information for a particular air handler.

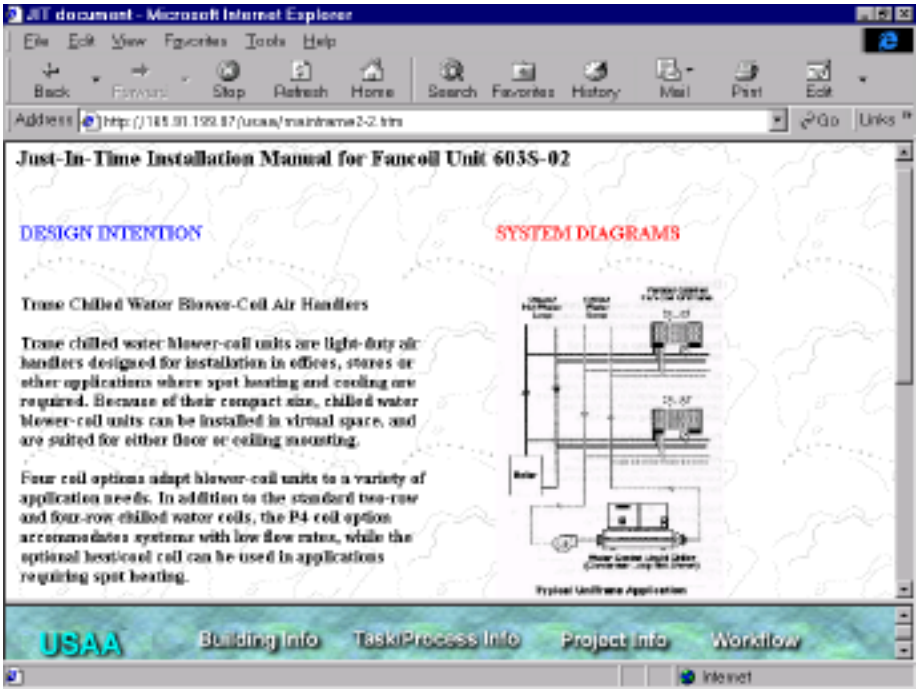

Figure 3. JIT operations document for training information for an air handler

5.2.4 Automated workflow management

The workflow management component of our prototype delivers work reports, notices, and feedback to the responsible people. Reports are usually sent to the facility managers for their management purpose or strategic planning. Notices are sent to the people affected by shutdowns, remodelling or emergency repair. The feedback is notification that information must be up-dated, due to either changes in the facilities that must be recorded in documentation or errors that are detected in the documentation.

The workflow management has been implemented using scripts embedded in the Active Server Pages. The scripts include automatic generation of e-mail messages. They also include execution of redlining software so that a user can annotate drawings with update information. We have used CADViewer by ArNoNa Internet Software Inc. redline DWF files (ArNoNa 1998).

6. CONCLUSIONS

By discussing with operations personnel, exploring related initiatives, observing innovative practices at several facility operations organisations, and constructing software at an experimental level, we have clarified the issues and solutions by which designers and constructors can deliver facility information to support operations. Our research also raises additional questions that can be addressed in further research. However, our efforts have already produced contributions upon which other researchers and facility managers can act.

6.1 Further research

More research could further sharpen our image of future facility operations support systems and address problems that currently lack clear solutions. In particular, further research should address the development of industry-wide standards, exploration of representations of design rationale, and quantification of costs and benefits through trial implementations. Opportunities exist to team with other organisations to leverage research and development investments.

Our continuing studies involve contacting a broad range of companies that either deliver or use facility information that are employing what may be termed “best practices” in the industry. Because we are interested in identifying innovators in the use of information technology in the AEC/FM industry, the people and organisations we plan to contact cannot be determined prior to our survey. We plan to begin by contacting those people and organisations who are involved in thinking about or implementing innovative solutions in facility management and real estate. We then plan to ask those individuals for their recommendations as to whom we might talk with next. If the opportunity and need arises, we may conduct site visits to learn more about an organisation or particular solution or problem.

Our concepts of a just-in-time operations document system could be explored more thoroughly by constructing a more advanced prototype. By focusing upon just a few work processes or tasks in operations, additional knowledge could be gained regarding cost of implementation and benefits.

Knowledge of intranet development tools should be distributed among key staff in facility management organisations. A practical understanding of the technologies underlying those systems will enable better decisions. It can also equip personnel with the ability to maintain or even customise vendor-supplied systems to better conform to internal practices. We are examining the viability of facility management graduate programs and continuing education courses that could focus upon applying information technology.

This study has begun to give us an informal understanding of the costs and benefits of new facility operations information systems. A next step in moving toward practical systems may be to develop a qualitative model of costs and benefits. The qualitative model could then be tested by quantifying it for several small test cases.

Additional research is necessary to establish useful standard structure and content for design rationale. We are exploring the use of XML as a medium for recording design rationale for use in activities downstream of design.

6.2 Contributions

Web technology can be used to produce on demand facility documents that are tailored to particular tasks and needs. A just-in-time facility document system could meet a variety of needs, such as training, trouble-shooting, and work-flow management.

The facility information for such a system may be recorded in digital formats that are not dramatically different from current industry practices. By holding the information in relatively generic repositories, the costs of delivering information from numerous external consultants can be reduced. It is reasonable for a building owner to establish standards for delivery of facility information from consultants. Facility information should be acquired as digital drawing files, spreadsheets, and Web documents. Scripts and Web server programming can then adapt the information into documents that are tailored to particular operations uses.

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