USE OF A RELATIONAL DATABASE SYSTEM TO INTEGRATE PRODUCT AND PROCESS INFORMATION DURING CONSTRUCTION

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ABSTRACT

The facility product and process model created during design and planning evolves over the life-cycle of a facility project, from planning & design, construction, operation & maintenance, to renovation/demolition. Integration of product and process models is required to represent process knowledge associated with product information so that richer semantics can be provided, and consistency and integrity of project information can be improved. This paper presents a conceptual data model for integrating a building product model with a process model. Product and process information during the construction phase is the main focus of this paper. The construction stage plays an important role in high quality information management for a project, because it is an intermediate stage between the design phase, and operation and maintenance. Complete as-built information and lessons learned which are captured during construction and associated with design components can contribute significantly to those involved throughout the life-cycle of a facility project. Current research efforts focus on information management based on multiple points of view and the management of changes and updates to integrate product and process information during construction. A grouping mechanism was adapted from previous research performed at the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL) to associate a building product model with the process model at the lowest level. This grouping mechanism allows a user to group components according to the work zone, bid packages, and then relate the group to activities. Based on the conceptual model, a prototype system was developed by using relational database management system (RDBMS). This paper presents the conceptual model, prototype system, and outlines our future research plan to integrate product and process information using an object-oriented paradigm.

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INTRODUCTION

Information is created in various formats throughout the life-cycle of a construction project, from design, through construction, to facility operation and maintenance (O&M). Information is created and used during the project life-cycle by many participants at different times. Construction managers/general contractors need to keep track of design and construction changes and as-built information in order to control and monitor construction progress. Facility operators/maintainers need accurate as-built information and drawings which reflect design/construction changes made during the construction phase. Increasingly, facility operators/maintainers are using computer-based facility management systems. Collection and management of the various types of information in an electronic format during design and construction will enable construction engineers and facility operators/maintainers to access information when they need it. In order to provide a smooth information transfer from the construction phase to the facility O&M phase, it is necessary to develop tools to help resident engineers manage design and construction information electronically in a consistent manner.

This paper presents the development of a relational database model and a prototype system which integrates design and construction information. The relational database model is designed to support collection of consistent and accurate information for building construction projects. The prototype system uses existing relational database management system technologies to capture as-built information and to provide multiple ways to access desired information.

EXISTING COMPUTER-BASED CONSTRUCTION MANAGEMENT TOOLS

Primavera Project Planner™, Expedition™, and Timberline Collection of Estimating Software™ are among the most widely used software for construction. Primavera Project Planner™ is project management software. It focuses on CPM scheduling, resource allocation and leveling, cost control and report generation. Primavera Expedition™ is software which supports project management. It keeps track of most administrative information needed by the owner, contractors, and subcontractors during construction. The information includes submittals, changes/modifications, bid packages and contracts, purchase orders, daily logs, etc. Timberline Precision Collection of Estimating Software™ is cost estimating software integrated with AutoCAD™ and Primavera Project Planner™. Resident Management System (RMS) is the Corps of Engineers standard system used by resident engineers to manage construction projects and administer contracts.

In addition to these commonly used computerized systems for project and control, several USACERL research prototype systems such as MULTROL (Liu et al. 1994), CADCON (Stumpf et al. 1994), and Schedule Generator (Ganeshan et al. 1995) were

developed to enhance or complement the features provided by the commercial products and RMS.

MULTROL

MULTROL is a prototype multimedia project control and documentation system developed by the University of Illinois and U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL). MULTROL provides documentation and management of project information in various formats such as text, video, sound, and images (Liu et al. 1994). Since MULTROL is intended to be used by a schedule engineer, the captured as-built information is associated with activities. Access to the as-built information is activity based. Users may input the daily activity description, cautions and problems, or lessons-learned in a text format. Video, sound, and images allow construction engineers to capture construction progress or problems more vividly. This system provides schedule engineers with fast and easy access to the as-built information so that they can detect potential delays and cost overruns. Also, MULTROL will allow construction engineers to communicate up-to-date progress reports and potential problems to their managers or others over a modem or computer network.

CADCON

CADCON is a prototype construction information retrieval system based on 3D CADD objects. This application was developed to see how CADD systems can be used effectively by resident engineers during construction (Stumpf et al. 1993). A CADD system, AutoCAD R.12 for Windows, was integrated with a relational database management system (RDBMS), Microsoft ACCESS. A conceptual data model was developed to link activity, cost, as-built pictures and specifications to 3D objects. Linkage between the CADD system and the RDBMS makes it possible to retrieve the related construction information on activity, cost, as-built pictures, and specification documents by selecting a 3D object in the CADD system.

Schedule Generator

Schedule Generator (Ganeshan et al. 1995) is a prototype application developed in a collaborative decision-making process environment (Golish 1994). The Schedule Generator uses a model-based planning approach to generate a preliminary construction plan including both time and cost components based on the design generated by the architect. The plan generation process has the following steps (see Ganeshan et al. 1995 for details): (1) define construction zones and groups of components; (2) generate activities; (3) identify construction methods for each activity; (4) assign resources for each

activity from MCACES (MCACES 1992) databases; and (5) sequence activities. Knowledge-bases are used to assist in various steps in this process. This system enables designers or constructors to evaluate what-if design scenarios in terms of construction time and cost, and to verify the constructibility through schedule visualization.

Need for Information Integration

The existing computer-based construction management tools seem to provide a wide variety of functions to manage design and construction information. However, the information integration has not been ideal in current practice. In many cases, product and process information related to construction projects is stored in different formats, and information exchange generally takes place at the file level, which has caused problems in interoperability between different management systems. There is a need for more tightly integrated information management to enhance the data integrity, provide data consistency and reduce redundancy. Using a relational data model, a first attempt was made to integrate existing systems. The following sections describe the relational data model and a prototype system based on the model.

RELATIONAL DATABASE MODEL FOR INTEGRATING PRODUCT AND PROCESS INFORMATION

A new data model was created to integrate existing product and process information stored in various computerized systems. This model represents a new way of information integration which allows design information in CADD to be integrated with a construction information framework. The purpose of this model is to build an information framework to capture, store, retrieve, and manage the as-built information, including multimedia data types, and to provide facility O&M personnel with accurate construction information. Figure 1 shows how the product and process information is integrated, using an Entity-Relationship diagram. The conceptual model helps organize the construction information such as component, cost, activity, changes, etc. Names on the box represent information types and names on the diamond represent relationships, while lines and arrows represent the type of the relationship.

Building components and process information are linked via a grouping mechanism, where the system user can associate a collection of components with a list of related construction activities. This grouping mechanism can be done by associating components and activities individually or by work zones, where a group of components can be selected to link with an activity (or activities).

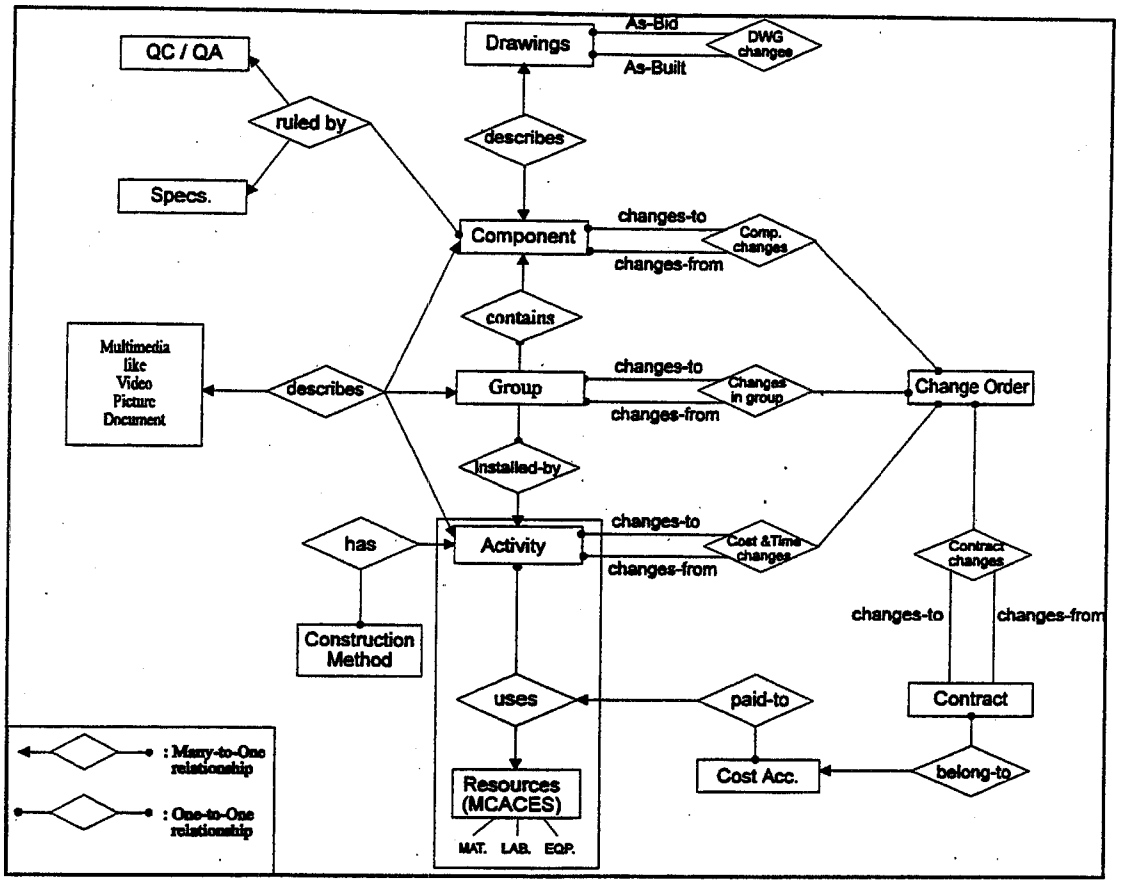

Figure 1. Relational Database Model for Integrating Design and Construction Information

The activity information has a one-to-many relationship with the resource information because many resources such as crew, equipment, and material are involved in one activity. An activity (or construction method in this model) is performed in a certain way, and influences the resources for the activity. Resource information was adopted from the MCACES database. MCACES is used as a historical cost and productivity database system by the US Army Corps of Engineers (MCACES 1992).

Change orders are considered as an information type to reflect changes during construction. Change orders usually involve changes to cost only or both cost and time (Hester et al. 1991). Also changes to component information can occur. Therefore change relationships were set up for component, component group, activity and contract types, and these relationships are associated with the change order type. The component information and the component changes relationship will keep track

of the history of changes, and the same mechanism can be applied to component group, activity, and contract information. The group information and changes to group relationship will be very useful when a change order contains changes to many components. Capturing changes during construction will help construction engineers monitor the construction progress more effectively by providing more accurate information , and will help capture information for facility O&M.

Multimedia information is related to component, component group, and activity so that it can be accessed from activity, component or component group. Supporting multiple relationships with activity, component, and component group enables users to access appropriate information from various viewpoints, and provides better semantics between multimedia information and activity, component or component group. Documents are also considered to be a multimedia information type so that O&M manuals, product information and warranty information for a specific component (e.g. HVAC equipment) can be stored in the database for use during facility O&M.

Specification and QC/QA (quality control/quality assurance) information are considered at the document level only. Drawings are considered as a separate type and changes between as-bid and as-built drawings are kept track of using the DWG changes relationship shown in Figure 1.

DEVELOPMENT OF CAD/CONSTRUCTION INFORMATION MANAGEMENT SYSTEM (CADCIMS)

System Integration

Based on the conceptual model described in Figure 1, a prototype system, CADCIMS was developed using Microsoft ACCESS™ V. 2.0, a relational database management system in the Microsoft Windows™ environment. Figure 2 shows how CADCIMS is integrated with existing commercial or research prototype systems. To present graphic information on components, CADCIMS integrates AutoCAD™ R.12 for Windows through DDE (Dynamic Data Exchange) and ODBC (Open DataBase Connectivity). GCLISP™, AutoLISP™, and Visual Basic™ have been used to build the interfaces among the Schedule Generator, the CADD system, and the database. Microsoft Project™ shares a database with CADCIMS to provide construction schedule information generated by Schedule Generator. MCACES is linked via ODBC to provide historical cost and productivity information.

Even though the general RDBMS had some difficulties in supporting multimedia data types, the introduction of object linking and embedding (OLE) developed by Microsoft has resolved this problem to some extent. Almost any kind of data including document, images, video, sound, etc. can be embedded as objects in the database in Microsoft Windows environment. As a result, multimedia type data in the

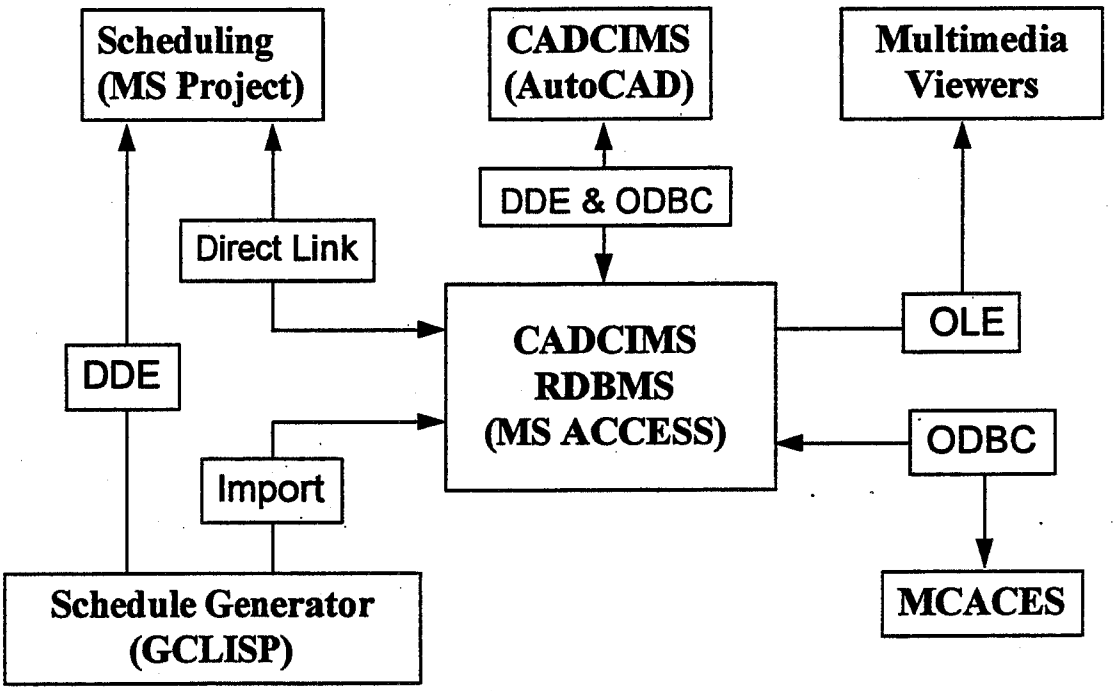

Figure 2. System Integration Diagram

CADCIMS conceptual model is stored in the relational database. Storing pictures, drawings, and specification documents in a database has more advantages than storing them in separate files because users do not have to manage both the database and files, resulting in improved consistency and security of the database.

System Implementation

Based on the conceptual model in Figure 1, entities and relationships were mapped into separate database tables in CADCIMS. CAD and Construction Information Management System (CADCIMS) currently supports the management and collection of as-built information on components, construction activities, and related multimedia information such as construction photographs and video clips. Management of changes to construction information is still under development.

Taking advantage of relationships between entities, CADCIMS provides multiple ways to access desired construction information from an activity, a component, or 3D component model in AutoCAD.

Figure 3 shows information access based on activities. To keep the consistency of schedule information, activity information in CADCIMS is read-only. Activity information can be managed in a scheduling system (MS Project) only. When a user

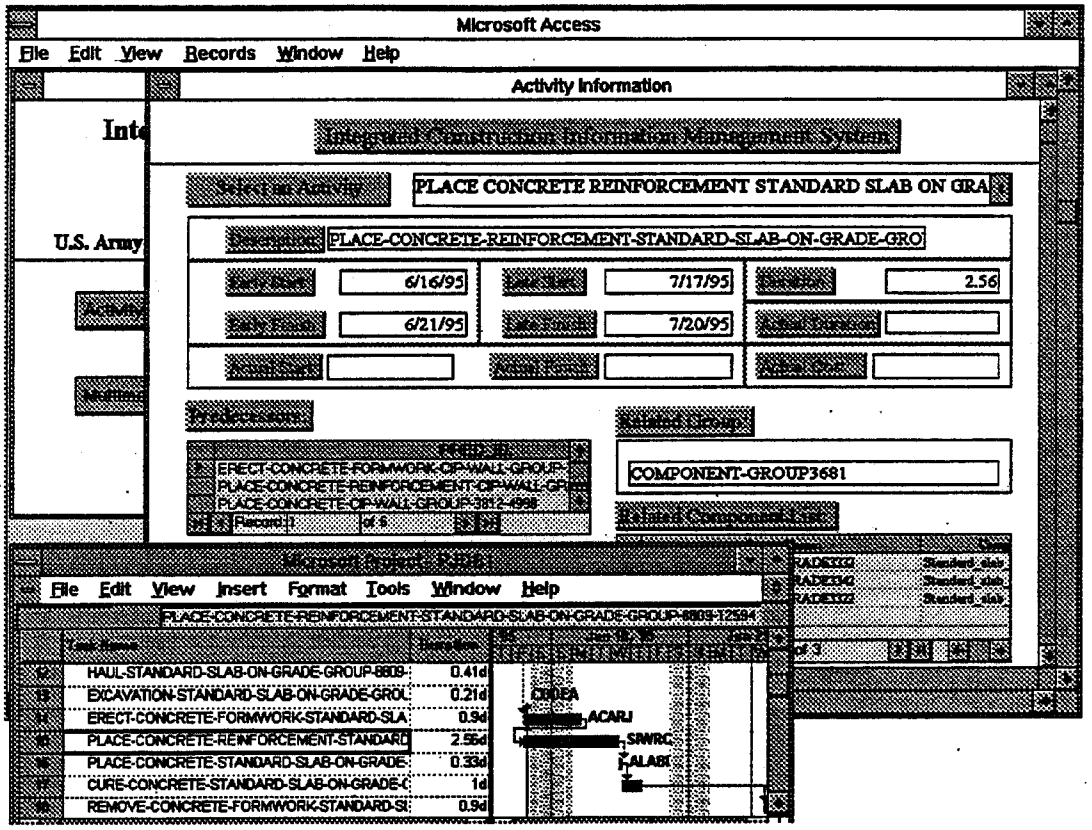

Figure 3. Activity-Based Information Access

selects an activity, the detail information of the activity such as early start and finish dates, late start and finish dates, actual start and finish dates, predecessors, related component group name and the component elements, and related multimedia information are displayed. More detail information on predecessors and components can also be retrieved and managed.

Figure 4 shows component information management from 3D component objects in AutoCAD. AutoCAD stores graphical data for components, while CADCIMS stores non-graphical data of components such as material information. Graphic and non-graphic data are linked by sharing the primary keys in the component database table. When a user select an 3D object in AutoCAD, the unique key of the object is sent to CADCIMS via DDE, then the corresponding information is displayed in CADCIMS. The component information consists of component description, related activities and installation schedule, related cost items and total cost, and related multimedia information. As shown in Figure 3, more detail information on schedule cost and multimedia information can be retrieved and managed.

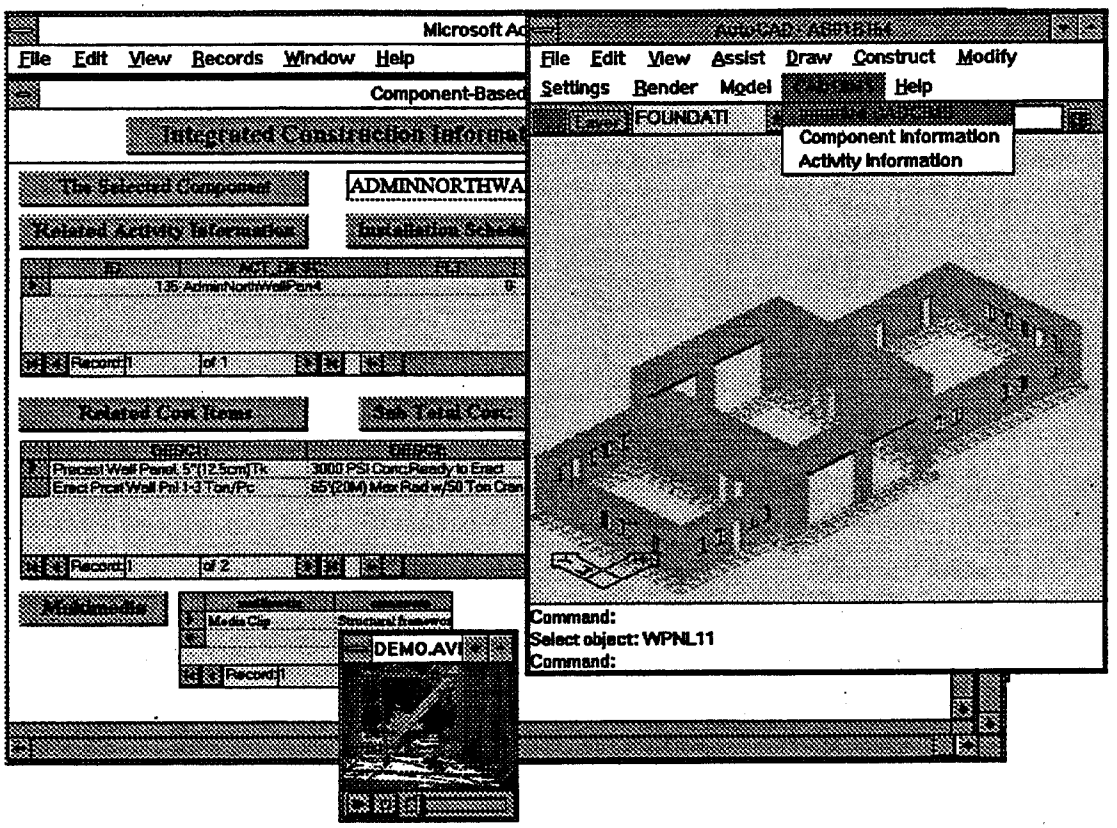

Figure 4. Component-Based Information Management

This section showed two implementation examples; activity-based (process-based) information access and component-based (product-based) information access. By integrating a building product and process information, support for multiple ways to access/manage desired information was accomplished, while improving information consistency and reducing redundancy. CADCIMS allows resident engineers to capture up-to-date as-built information, analyze progress and helps during decision making. Structured and efficient information storage would help improve information transfer to facility operators/maintainers.

FUTURE STUDY

This research provides feedback on the feasibility of integrated process and product models, system integration, and existing software technologies such as database and CADD systems. Taking advantages of the object-oriented paradigm, we are extending the scope of the CADCIMS model by adding construction information types to support the evolution of construction project information throughout the life-cycle. We have found that object-oriented technology provides a more consistent

development paradigm throughout modeling, programming, and database development with robust concepts such as class, inheritance, aggregation, and version management despite difficulties in programming and immature object-oriented database standards.

The goal of the future model is to support smooth information flow across different phases of a project life-cycle, providing feedback and improvements based on knowledge and lessons learned during design, construction, operation and maintenance, and rehabilitation (refer to Figure 5).

CONCLUSIONS

Based on existing research such as MULTROL, CADCON, and Schedule Generator, a conceptual data model and prototype CADD-based construction information management system (CADCIMS) was developed to capture and manage the as-built information during construction and to provide smooth information transfer from design to construction and to facility operation and maintenance.

CADCIMS allows resident engineers to access construction information from both 3D CADD objects and the database. Users can access the desired information from different views, such as building component, activity, component group, drawing, contract and change orders. Changes can be automatically updated and the impact of a change can be evaluated more precisely. It helps resident engineers monitor and control construction more effectively. Database consistency was improved by

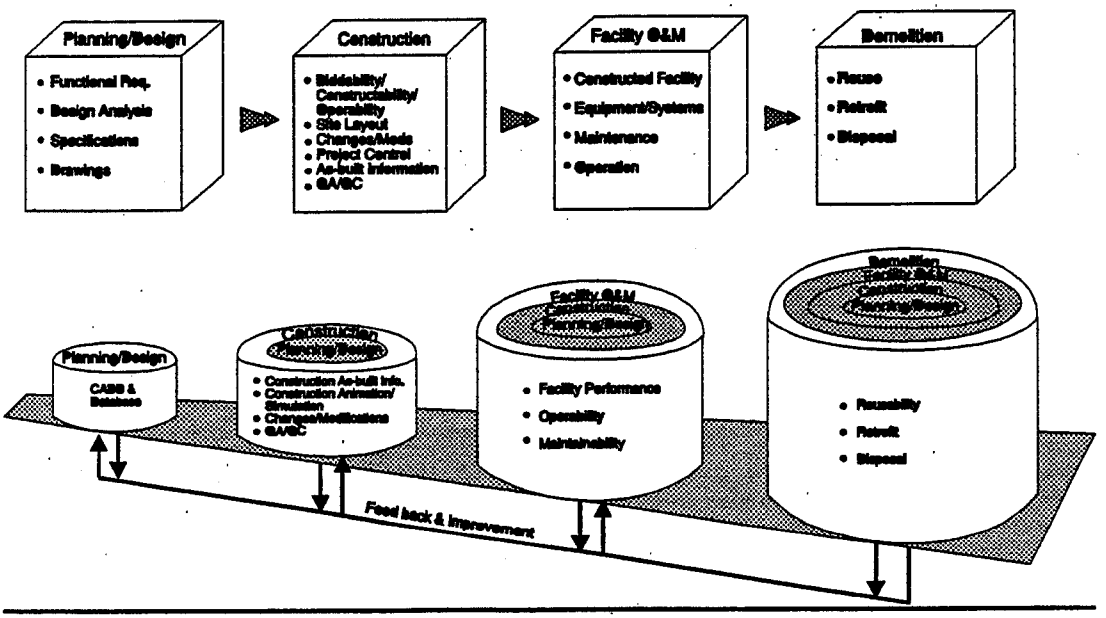

Figure 5. Life-Cycle of Project Information

embedding the multimedia information into the database. Up-to-date construction information can be transferred to facility operators and maintenance personnel with minimal effort, so that the information can provide corporate knowledge of the facility for O&M, renovation, demolition, and future projects.

CADCIMS demonstrates how design and construction information can be integrated, and that life-cycle information management from design, to construction and operation/maintenance may not be too far away.

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