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Computer aided facilities management and design

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Case Studies for Computer Aided Facilities Design and Management

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Computer Aided Facilities Management and Design

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Design is one of the most widely recognized of all activities that impact the creation of buildings. However, it is not the only or the most lasting one when we consider the "lifetime[11] of buildings. Often, maintenance of physical plants, equipment, and furniture; development of plans for use, reuse, and renovation of buildings figure more prominently into how buildings are used and conceived. This is an area which is under-represented and underdeveloped in the area of computer aided design (CAD).

A large amount of information is generated by architects and engineers during the design, working drawing and specification writing activities . This information is also needed during the facilities management process and therefore by computation based facilities management systems. Under ideal conditions, a CAD based design process would automatically create data that can be used directly by facilities management applications. Currently, there are very few systems that make this interaction seamless or easy.

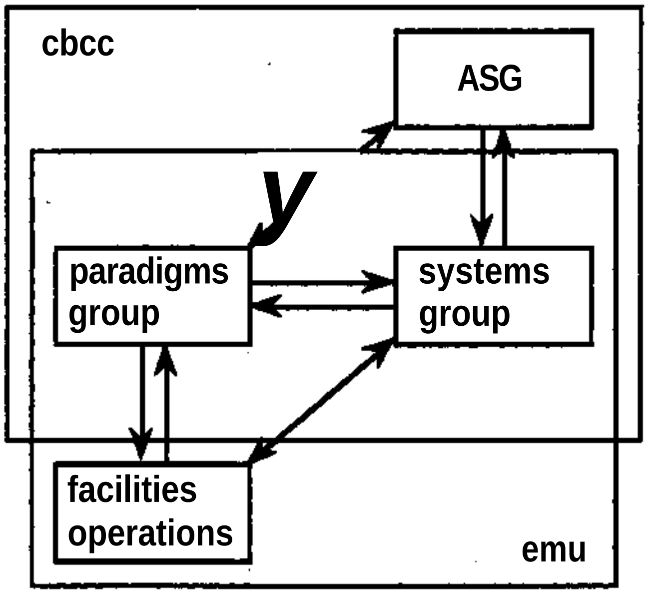
There are numerous inefficiencies arising from redundant representations, difficulties in information gathering, and costly error recovery tasks. Furthermore, the fact that these tasks are typically stretched over long periods of time makes the already complex information and communication problems even worst. This project envisions seamless and redundant-data-free applications supporting facilities management systems that can assist both the designer and the facilities manager.

Approach

This project is being conducted to deal with two problems simultaneously: the potential use of an integrated database by the Carnegie Mellon University's (CMU) design and management staff for its facilities operations; and the further development of on AutoCAD based CAD software environment called ASG-TTMS as a facilities design and management tool.

Our overall strategy is to build a relatively large system up from individual modules that respond to specific design and management tasks. Presently work is being done on a rapid prototype based on the CMU facilities management and design operations, the Margaret Morrison Building, one of the academic buildings on the CMU campus, and the ASG-TIMS facilities management and design software.

Our approach is to use two parallel research strategies in collaboration: 1) evaluating and modeling the facilities design and management processes; and 2) designing computer systems that implement these models and respond to these evaluations (Figure 1).



Figurel: The organization of the research groups and institutions. Arrows indicate flow of communication between independent entities of research and practice .

The collection of papers included in this volume represent the former effort, namely our present attempts at describing and modeling the various use types that we are likely to encounter in the area of Computer Aided Facilities Management and Design (CAFDaM). The findings are intended to inform the latter, the system development group, and enable an approach that is responsive to user as well system requirements.

While some of the studies included in this volume were motivated by circumstance and opportunity, we consider them useful building blocks of an empirical foundation for developing use paradigms for CAFDaM. The first study is one that provides a survey of the CAFDaM systems in use at US universities. The second one is a case study of the FDaM operations practiced by the Design and Construction Office at CMU. The third is anothercase study, exploring possible connections between the use of CAD and reductions in the number of change orders issued. Finally, the fourth study included in here, deals with a specific user application domain: space allocation, involving the College of Fine Arts facilities at CMU.

Benefits

The long term benefits we expect from this research effort include but are not limited to the improvement of the information exchange between design delivery and facilities management processes. We anticipate that clients will be able to obtain accurate, electronic, building description data, much more efficiently, as an output of the design and production process for use in facilities management; and be able to use such data in a seamless design delivery process.

We also anticipate that there will be longer term benefits in terms of the standards governing the representation of buildings as well as applications directed towards steady state building maintenance operations.

A Survey of Computer-Aided Facilities Management at Eight U.S. Universities

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In this survey, we focus on computer aided facilities management (CAFM) applications being used and developed at US universities. While our initial sampling included a much larger number of universities, we limit our reporting here to eight Examples of CAFM tasks and their use in these universities are summarized in Figure 1. In each case, while standalone computer applications are available for the majority of these tasks, there is a common tendency towards integrating these applications under one operational umbrella.

Figure 1 Computer Aided Facilities Management Applications at Other Universities,

	BMawr	IowaS	SLM'S	UCLA	UUtah	UWA	VATech	WSU
Billing			■		■			■
CADD								
Construction cost estimator							■	
Contract administrator								■
Custodial services					■			
Deferred maintenance backlog	■			■	■			■
Equipment control		■				■		
Equipment inventory		■		■	■	■		■
Energy analysis		■						
Fleet management					■			
Grounds inventory				■	■			
Key control					■			
Leasehold management								
Maintenance cost estimator	■							■
Material inventory	■				■	■		■
Personnel management	■				■	■	■	■
Preventive maintenance tasks			■	■	■	■		
Scheduling	■				■		■	■
Space inventory		■		■	■	■		■
Space analysis								
Space planning								
Work order generator	■		■		■	■		
Work history	■		■	■	■	■		■

Theoretically speaking, integration of CAFM applicationsreduces the amount of time and effort spent, and the number of potential errors that might be involved in duplicating data across departments concerned with facilities management. For example, the drawings created by the design department could be used by the space management personnel who could in turn share their space ownership diagrams with the maintenance management team to be used in maintenance planning and scheduling.

The same drawings could be used by the energy management department to generate reports on energy consumption on a square footage basis for a building's HVAC zones [Kimmel 1990].

CAFM at Eight U.S. Universities

In the following sections, we will discuss the computer aided facilities management implementations at eight US universities about which our survey contains the most detailed information: University of California, Virginia Polytechnic Institute and State University, Washington State University at Pullman, University of Utah, University of Washington, Bryn Mawr College, Iowa State University, and St. Mary's University. These institutions provide an interesting spectrum of applications of varying contexts and sizes, and utilize different technologies from databases to direct digital controls to bar coding applications.

University of California, Los Angeles, California

The Facilities Management Information System (FMIS) being used at University of California/Los Angeles is an "integrated system of computer hardware, software packages (modules), and data designed to provide timely information in support of routine and unique decision processes'[1] [Freeman 1987]. The UCLA FMIS was initiated with the need to accurately document the campus's deferred maintenance backlog. Although the inventory data base was compiled for deferred and annual maintenance funding justification purposes, presently, it is being utilized to support additional practical applications such as a deferred maintenance program, a preventive maintenance program, a computerized work order system, a component on work history information, project estimating support, and staffing requirements.

The FMIS consists of a number of modules. The *deferred maintenance backlog* module keeps track of deferred maintenance and capital renewal tasks and work in conjunction with the maintenance cost estimator to schedule and manage maintenance and repair tasks. The facilities *inventory* module keeps track of all facilities systems (buildings, grounds, utilities) and components for the daily operation and maintenance of the physical plant. Applications include preventive maintenance, custodial planning, relamping and painting. The *maintenance inventory* module keeps track of equipment that is in the preventive maintenance management system, a subset of the facilities inventory. The *preventive maintenance tasks* module specifies and schedules preventive maintenance work on inventory components. The *space inventory* module keeps track of the "space planning" attributes of a room. It allows the facilities manager to list all attributes of a room necessary to plan its use or assign a function to the available inventory of space. The *work history* module works in conjunction with the other modules to keep record of all maintenance and improvement work performed at the inventory component level.

Other modules in development include an *accounting* module that works in conjunction with the organization's existing financial accounting procedures, a *graphic index* of the data bases, a *contract administrator* that allows the facility manager to manage the work performed by outside contractors, a *construction cost estimator,* and an *energy analysis* module. Additionally, there will be a *growth projector* that works in conjunction with space planning to allow the facility manager to simulate facility growth and study the impact on space requirements and operations, a *leasehold management* module, a *maintenance cost estimator*, a *material inventory* module, a *personnel management* module, a *planned maintenance* and an *improvement* module that combines all financial requirements into a pro forma cash flow scenario. Further, there will be a *scheduling* module, a *space analysis* module that provides the facilities manager the tools to analyze the efficiency and usage of the facility, a *space planning* module that provides the information necessary to plan the usage of the facility, a *work order generator* that interfaces with other modules to print out work orders to be given to staff performing the work and to feed back completed work to the work history module.

Freeman [1987] notes that the FMIS is valuable to the physical plant administrator in terms of decision support and improved communications. The FMIS supports links between maintenance administration and shop administration; shop administration and shops; shop and craft shop; maintenance administration and planning administration; work control and facility users; and maintenance administration and institutional administration. Freeman adds: "Automated systems, managing reliable facilities information, have led to substantial productivity increases, improved decision making, and ultimately reduced operation and maintenance costs.[1]*

Virginia Polytechnic Institute and State University

At Virginia Polytechnic Institute and State University, the renovation work done annually is worth more than $5 million. Through the 1980's, its estimating and scheduling activities were automated. Typically, the estimator for a renovation job might be concerned with issues such as existing mechanical or electrical components in a wall that is to be torn down, the cost premium on the materials designed into the project to "match existing," and the practicality of only painting the new wall and leaving the existing walls as they are. The scheduler, on the other hand, is concerned with the interruption of classes or research, and coordinating the project activities with the material deliveries due to limited on site storage space.

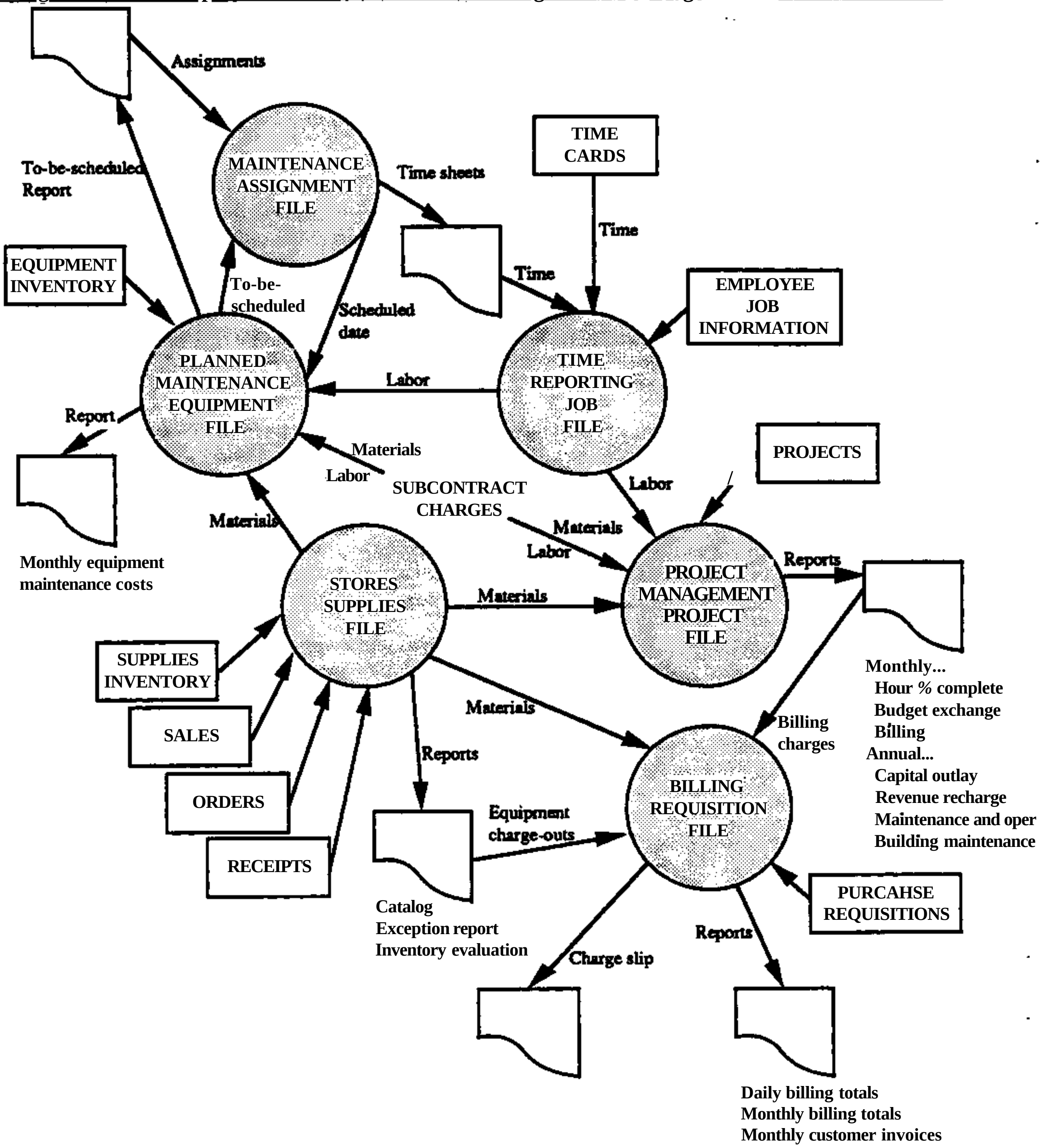
Since an estimate is always required before any work can be authorized and the information is often wanted within a few days time, it is essential that estimating be able to promptly address multiple projects. There are three (mechanical, electrical and structural) estimators equipped with a personal computer and digitizer board, and utilizing a construction estimating software package. While the computer provides speeded-up estimating procedures, the availability of clear and concise printouts proves equally useful in a number of areas (i.e. defending the estimates even when the person who actually prepared the estimates is not available; basing material orders directly on the estimates' copy; using the printouts as work order sheets in very small projects).

Thus, automation also allows the scheduler to address a number of projects simultaneously. Computerized scheduling provides the ability to modify line items as needed and have the entire schedule updated instantaneously. Another advantage is the ability to quickly look at alternative scheduling scenarios and determine the most advantageous plan, This search is almost never made using manual methods since it requires too much time and effort. A third important advantage is the ability to look at the work force across several projects and make sure that the staff is not overcommitted. Use of resource management reports allows the monitoring of work progress and comparing it to initial estimations. This also allows the managers to project the outcome of a project early on and alerts them to any problems that may affect the schedule and budget before they become critical [McCoy 1990].

Washington State University, Pullman, Washington

The computerized planned maintenance system at WSU/Pullman (Figure 2) integrates activities in scheduling, time reporting, project management, stores inventory and billing. This system keeps track of maintenance history for each equipment in four categories: preventive maintenance, repairs and call-backs, materials, and subcontracting. A system feature provides flexibility in assigning the workload according to available staff. Equipment maintenance is carried out on the basis of equipment use as well as calendar date inspection and service. Maintenance schedules ate used in determining due and scheduled maintenance tasks *versus* deferred tasks. Monthly and annual reports provide summary information. Management uses this information in planning and also defining staff requirements based on objectives. Maintenance and deferred maintenance statistics justify budget requirements and aid in selection of areas for budget increase or reduction. The planned maintenance system at WSU/Pullman has reduced repair costs and has assured top management that maintenance schedules are being met The system, when integrated with the project management and inventory management systems, will include all physical plant services at WSU/Pullman. Expansions to the system are planned for structural maintenance, custodial services, and vehicle maintenance [Jacobs 1988].

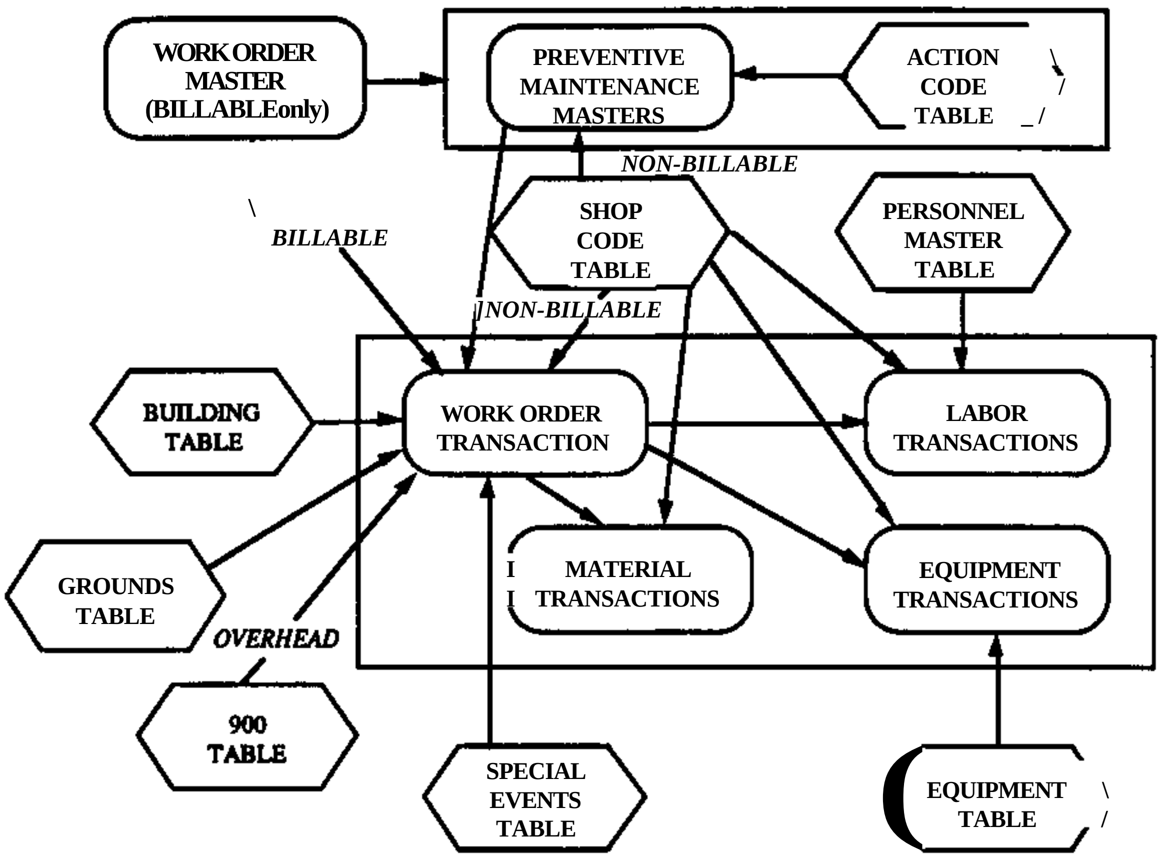
Figure 2: The Computerized Planned Maintenance Program at Washington State/Pullman.



University of Utah, Salt Lake City, Utah

At University of Utah, a decision was made to develop a system that would provide support in work planning, work control, work review, and cost accounting. The system developed is called the Information Retrieval, Management and Accounting (IRMA) system (Figure 4.2). IRMA provides support in the following maintenance management tasks: preventive maintenance, key control, motor pool, capital renewal and replacement, deferred maintenance, custodial standards, and utility cost analysis [van der Have 1988]. The system, in essence, manipulates data in several databases such as facilities inventories to generate new information needed to accomplish a maintenance task. The databases are referred to as "tables" in Figure 3 and working files are created for generating work orders, bills and reports.

Figure 3: The IRMA System at the University of Utah.



University of Washington, Seattle, Washington

Maintenance managers at University of Washington/Seattle, concerned with the valuable labor time wasted and the amount of error introduced in the process of manual records keeping or the transfer of these manual records to the computer, decided to use bar coding to keep track of their maintenance activities. Considering the data management problem they had at hand, the managers decided to start with a pilot program for the maintenance of the 6,000 portable fire extinguishers on campus. Since all equipment on campus already had a unique digital identification (DI) number describing what building the item is in, what floor it's on, what kind of system or unit it is, and which of the several similar

units on the floor it is, they used the DI numbers in creating bar code labels. These labels were placed on the extinguisher stations, individual extinguishers and the replacement stock. An interface program was written between the bar code program and an inventory program that was already in place. The fire marshals were also given an employee bar code. Each week a fire marshal starts his rounds by reading in his employee bar code. Next, he reads in the fire extinguisher station and then all the fire extinguishers at that station in a certain sequence. At the end of the day, the bar code is downloaded and the information is entered into the data base. The same bar code reading and downloading process applies when the extinguishers are replaced with new ones from the replacement stock [Heinz 1987]. Because the bar code system is so precise, the University is now working with the local fire department to abolish the need to check and paper tag each extinguisher.

Bryn Mawr College, Bryn Mawr, Pennsylvania

At Bryn Mawr College, a computerized work and inventory control system was installed to provide management with the capability to closely analyze work and material flow. The information available from the system helps in the identification of problem areas in work control and concentrate efforts on correcting them. The computer system helps keep track of backlog items, scheduling of work, progress/productivity reporting, material ordering, material withdrawal and cost analysis. Work supervisors no longer lose work orders in the shuffle or leave them unnoticed. The backlog listing does not drop any work unless it has been completed or canceled. All materials purchased are accounted for by monitoring the dollar flow from the stock room to the job site [Lash 1988].

Iowa State University, Ames, Iowa

Iowa State is among those universities that has invested in an extensive building automation system (BAS) for monitoring and control of equipment. Initiated in 1976, the BAS has been expanded with funding available from a total energy management program, to include fifty-five buildings. Over 3300 separate points, in distances of more than two miles, are monitored and controlled by direct digital control (DDC) equipment [Reynolds 1987].

St. Mary's University, San Antonio, Texas

At St. Mary's, management uses the People Oriented Information Systems for Education (POISE) software system. POISE is a series of programs designed specifically for creating and maintaining files of repetitive data, and St. Mary's is using it for keeping track of work orders. With the database loaded with information on work orders, the system is used to generate reports such as an incomplete work order report, monthly customer billing report, building maintenance history report and a dormitory billing report to the housing director. Other types of reports anticipated in the future include a shop productivity report, customer budget preparation report, and an automotive maintenance history report [Jenkins 1988].

Computer Aided Maintenance Management (CAMM) in CAFM

Computer aided maintenance management (CAMM) systems form a large subset of computer aided facilities management systems and thus deserve mention, before we conclude. Maintenance management simultaneously involves a number of physical plant operations such as facilities inventorying, time and labor scheduling, cost estimating, space management, energy management, and work order control. There are two main areas of concern in maintenance management: *preventive* maintenance and *corrective* maintenance. Preventive maintenance is the collection of planned maintenance activities, usually scheduled over a period of twelve months, and is agreed to be an effective means of prolonging equipment usefulness, cutting down on repair cost and achieving energy savings. Corrective maintenance is, on the other hand, what managers refer to as "putting out fires." Unlike preventive maintenance, it is not a scheduled activity. It includes those repairs made when equipment breaks down or a window breaks [Gold 1990].

There are four fundamental steps in maintenance management (1) inventorying facility equipment and resources, (2) determining what is to be done from the standpoint of maintenance practices and procedures, (3) keeping histories of all activities and occurrences and analyzing, results, and (4) making changes to continually improve maintenance operations, based on the analyses. A CAMM system consists of four distinct components: (1) generation of planned maintenance work orders, (2) generation of repair work orders, (3) an equipment database, and (4) a maintenance history database. The equipment and maintenance history databases provide the necessary information for the formation of an initial maintenance schedule. Then the planned maintenance and repair work orders are issued. Planned work orders are issued on a calendar basis while repair work orders are issued as requested. If the database can interface with a building automation system, then planned maintenance work orders can be based on actual equipment runtimes rather than the calendar, while repair orders can be generated in response to off-normal conditions rather than obvious breakdowns. CAMM provides a capability for not only scheduling work but also analyzing, managing, and optimizing it. The maintenance history database contributes to the third fundamental step in maintenance management. The availability of specific and precise reports can be used in the fourth step. For example, a failure analysis listing all failures over a six-month period is difficult to use if the information actually needed is related to a particular building [Kleismet 1987].

A survey conducted by Johnson Controls and Association of Physical Plant Administrators of Universities and Colleges (APPA) on planned maintenance cost savings and specifics of energy savings through use of planned maintenance and computer-aided maintenance revealed that a majority of the respondents used some form of planned maintenance, with manual systems being used by nearly two-thirds and computer-aided maintenance management (CAMM) systems being used by less than one-third. The results also showed that more than three-quarters of the respondents perceived significant savings resulting from the use of planned maintenance and these savings averaged about ten percent of their facility maintenance budgets. Energy savings were far and away the most important of all among savings resulting from planned maintenance activities. Equipment related savings were second and, combined with energy savings, comprised the bulk of all savings [Kleismet 1987].

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Case Study One

Facilities Management and Design at Carnegie Mellon University

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A review of the Woods Hole (NAS, 1986) model for an integrated database represents a point of departure for this study (Figure 3.1). This model represents a point of departure for this study, since it is based on the basic idea of supporting a design delivery activity with seamless processes and centralized and coordinated data about buildings. Our purpose is to investigate facilities management operations in order to better understand the activities that contribute to such a design universe. From this vantage point the Woods Hole model reveals two main fields of activities related to building life cycle: facilities design and facilities management.

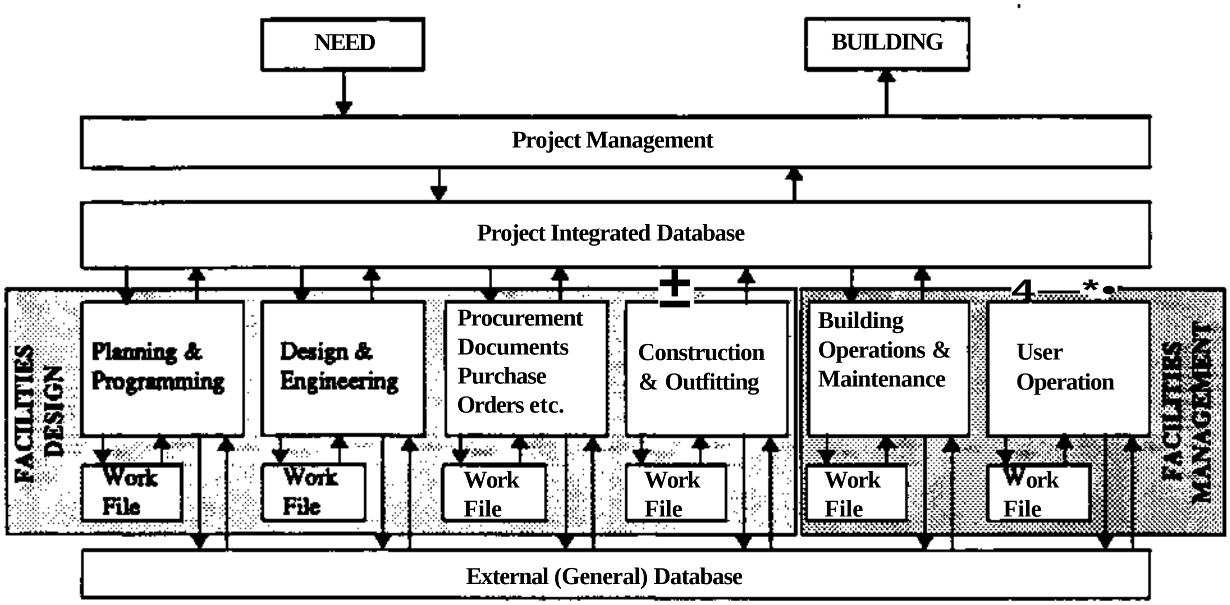

Figure 3.1 **Facilities Design and Management in the Woods Hole Diagram.**

In this case study, we present a bench marking study on existing facilities design and management processes at Carnegie Mellon University (CMU). The information gathered for this purpose is based on interviews with key personnel of the Design and Construction Office (DCO) of the Office of Physical Plant at CMU and analysis of related documents. The diagram in Figure 3.2 summarizes the existing processes.

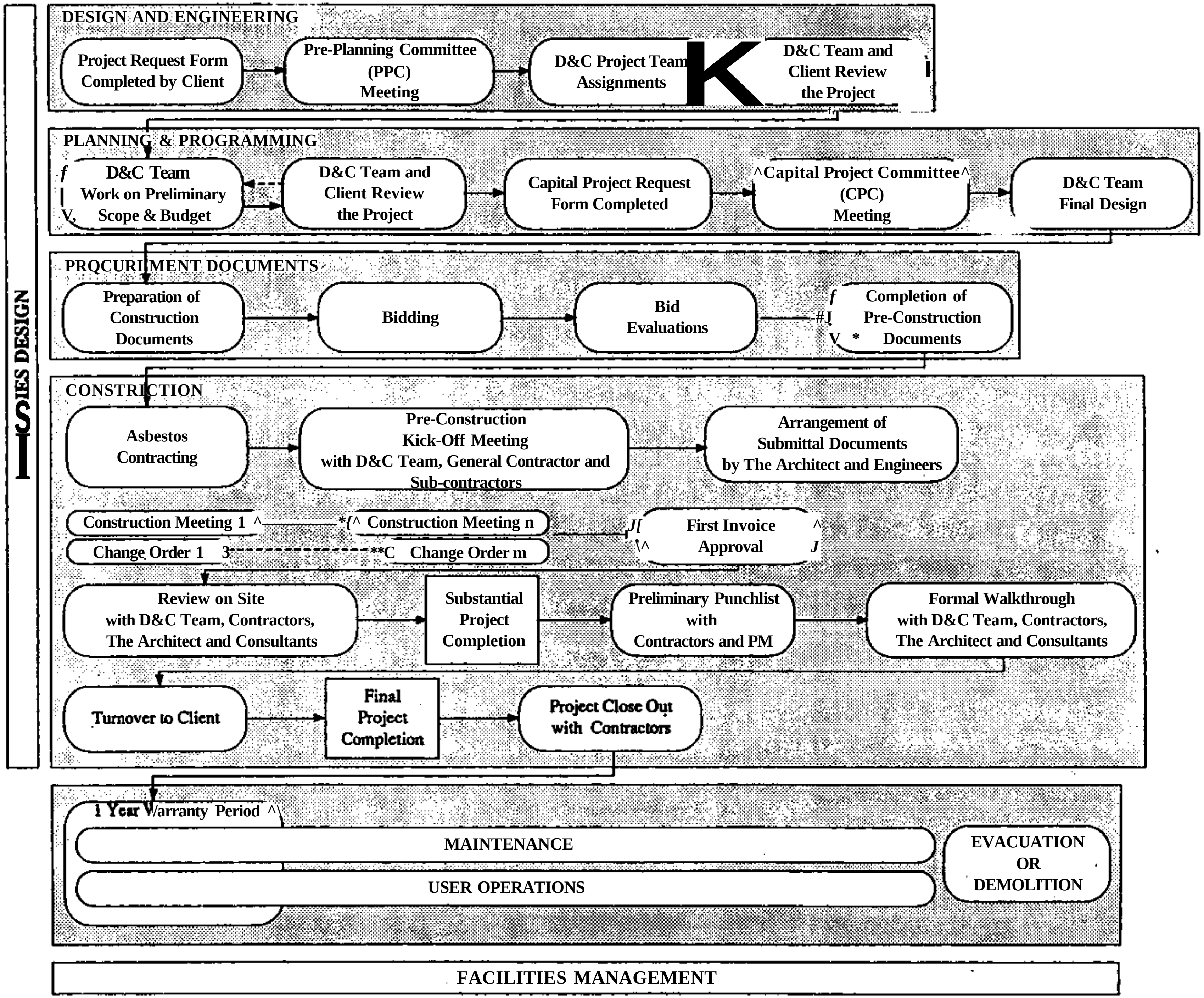

Figure 3.2 Facilities Design and Facilities Management at CMU

Facilities Design at CMU

The projects undertaken by the DCO vary from redecorating offices and classrooms, to renovating a wing of an existing building, to multi-million dollar capital projects (Figure 3.3). The value of renovation projects totals approximately $6 million annually and forms 60% of the University's total capital budget (Roach, 1992).

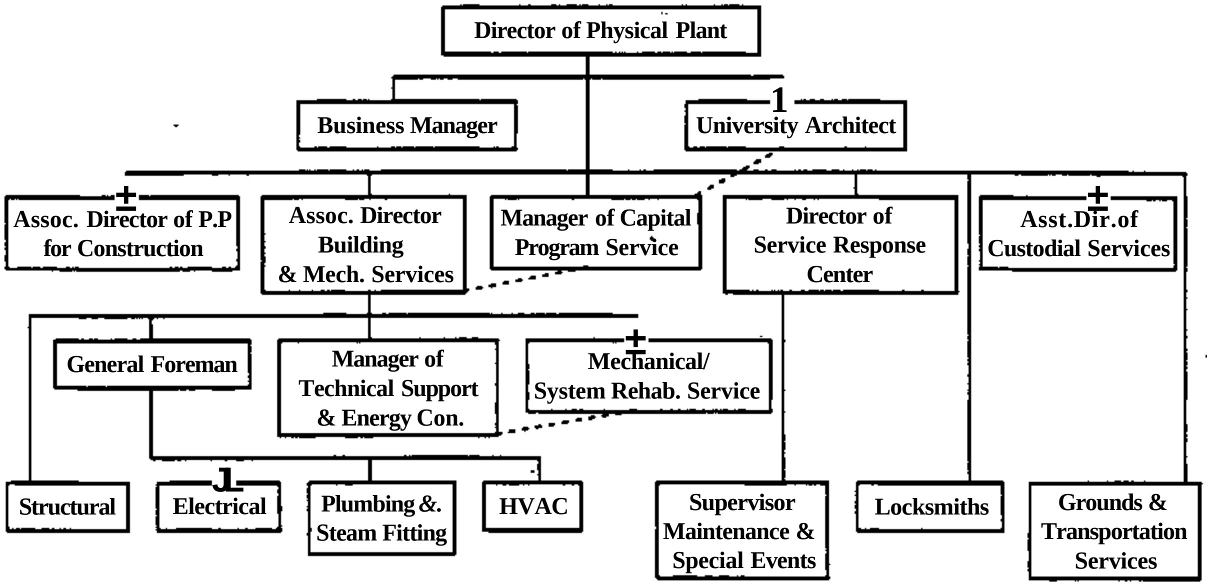

Figure 33 The CMU Physical Plant.

All projects are initiated with a Project Request Form. The requester of the project completes the form by including information about himself, a description of the project, the anticipated funding source, and the expected completion date. Any member of the university can request a project, but only a Dean or Department Head may sign the form. The Project Request Form is then turned in to the business manager at the Office of Physical Plant. DCO staff then review the scope, and attach to the form preliminary hours and fees that are needed to establish project scope as well as time and budget estimates.

The DCO uses two computer systems in project management. The first one is the Project Management System (PMS) running on the university wide administrative network Mirage; the second is a collection of in-house spreadsheets, created on a commercial spreadsheet package. Although the PMS provides useful reports on time and budget assignments, these reports are detached from each other and require more time to produce than the in-house reports which provide a better overview of all work in progress. The Business Manager can access both systems on-line. Project team members are provided with printouts of the reports.

Planning and Programming

The completed Project Request Form, together with a preliminary estimate of hours required to complete the project, are submitted to the Pre-Planning Committee (PPC). The PPC meets biweekly and consists of the following members: Associate Provost, Associate Vice President for Budget and Planning, Director of Physical Plant and Business Manager for Physical Plant. The committee is mainly concerned with the issues of (a) space ownership (i.e. the space or building in question being actually owned by the requester), (b) source of funds, and (c) design implications. If the project is a large scale capital project, outside consultants (coordinated by in-house staff) and the Design Review Committee of the university is involved in the evaluation of aesthetic criteria and the development of an architectural program for the project. For small projects, these tasks are undertaken by DCO staff. The PPC, after reviewing the request, approves the request or ask for additional information unless it has decided on denial of the request. Projects do not proceed onto the design phase unless approved by the PCG

Design and Engineering

Once a project is approved, DCO forms a design team and the first meeting is held with the client to define project scope, establish design criteria, and discuss schedule and budget objectives. If the project scope is feasible at this point, the DCO team prepares the sketch design and rough estimates to be reviewed by the requester. Similar to the planning and programming phase, DCO's design team collaborates with outside consultants on design issues if necessary. The typical organization of DCO design coordinators is shown in Figure 2.4. If the sketch design and the estimates are not within the available budget, the requester might discuss scope adjustments with the DCO team. With the user's approval, the DCO team completes the preliminary scope statement, sketch design, final estimates and the Capital Project Request Form to be submitted to the Capital Project Committee (CPC). The CPCs primary concern is to make sure that the project is properly funded. Its members include the PPC members with the addition of Director of Campus Services and Associate Director of Physical Plant for Construction. Once the project is approved by the CPC, it enters the University Capital Project Tracking System and is given a Capital Project Number by the University Budget Office. Upon receiving CPCs approval, the project proceeds into the final design and construction documentation phase.

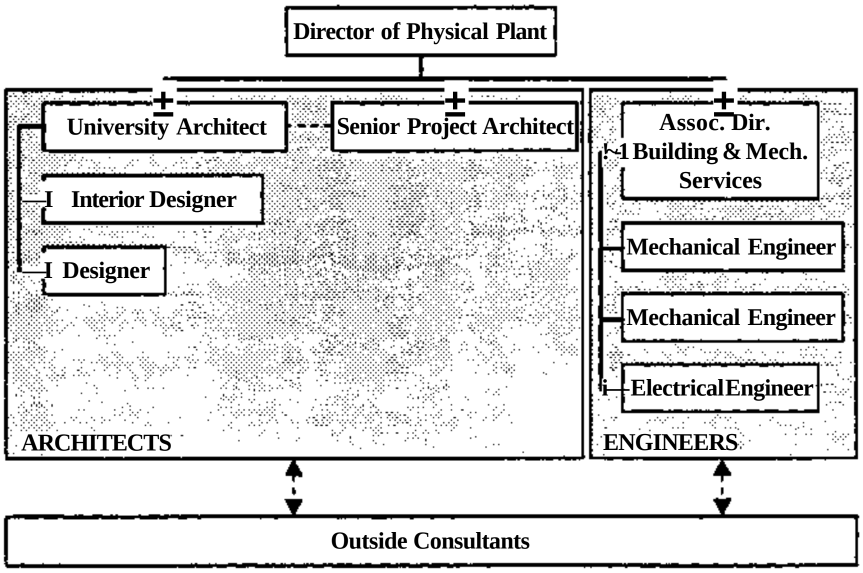

Figure 3.4 Design Coordinators at the Design and Construction Office

DCO has one machine dedicated to computer aided drafting. The system runs *AutoCAD* and is used occasionally; drafting is done mostly by hand. One major obstacle identified by the DCO designers is the lack of complete and precise as-built drawings of campus buildings. Although a computer tape containing all the drawings for the University's buildings does exist on campus, this media is not readable by any of the University's existing computer facilities. For very small projects, the designers have tried scanning existing printouts of these drawings obtained from the University Planning Office, then reprocessing them in a CAD package to be used as construction drawings. DCO also uses computer tools in specifications writing. The most recent version of *MasterSpec* on laser disc is used together with *Sweet's Catalogue.*

Preparation of Procurement Documents and Bidding

The selection and procurement of furniture and furnishings (soft costs) is undertaken by the in house DCO interior designer while all other hard cost items are procured by the contractors. As the construction documents are being completed, a DCO construction coordinator is assigned to monitor bidding, contractor work and construction activities, and communications with campus utility systems. Projects are bid to either general contractors or sub-contractors who are in turn managed by the DCO construction coordinator. Very small projects may be handled by in-house craftsmen.

Construction, Turnover, and Acceptance

The initial pre-construction meeting finalizes the construction schedule. Scheduling is even more challenging on an academic site; the construction coordinator strives to bring minimum disturbance to academic activities, as construction work is known to proceed more efficiently when the site is not occupied. However, the schedule might have to be planned around ongoing activities such as classes, exams, meetings and conferences. Conflicts between academic and construction schedules can cause delays and increase construction costs. Changes to the construction contract during construction results in change orders. Any change order not included in the project budget as construction contingency is reviewed by the administration. Frequent reasons for change orders include *unforeseen site conditions* such as existing building deficiencies uncovered during construction, and *changes in scope* such as additional work requested by the client or initiated by the construction coordinator.[1] The progress of construction activities is discussed in weekly or biweekly construction meetings held by the construction coordinator and the contractors.

The DCO coordinator assures that the work of the contractor is complete and that the project site is ready for occupancy. Systems are tested and maintenance staff and occupants are trained in their use. Move-in is also directed by the coordinator. Once a project is completed, all written documents pertaining to that project are collected in a Capital Project Master File.

A one year warranty period is in effect as of final project close out Feedback from the occupants is essential during this period both for enforcing warranties on unsatisfactory work or materials as well as for improving the performance of future projects. DCO is presently working on establishing postoccupancy evaluation policies for the university. The Manager for Capital Program Services at Physical Plant is contributing to the establishment of the University Standards and Inventory Management (USIM) Committee, aimed at promoting University wide use and management of standard materials and equipment.

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[1] See Case Study 2 for a discussion of change orders and the need for as-built drawings as a way to reduce change orders in the contracts issued by the Office of Physical Plant at CMU.

Facilities Management at CMU

Carnegie Mellon University maintains over 3300,000 square feet of space in thirty two academic/administrative buildings and twenty four residence halls standing on the 101 acre campus. The buildings are used by over 3,000 full time faculty and staff, and over 6,500 full time equivalent (FTE) students [Roach 1992]. Building operations and maintenance tasks at CMU are undertaken by the Service Response Center (SRC) at the Physical Plant while user operations concern a variety of departments in the University ranging from Telecommunications to the Office of the Registrar. With regards to user operations, we will be focusing on the issue of space management that is undertaken by the University Planning Office.

Building Operations and Maintenance

The SRC forms the "communication hub" of the Physical Plant by acting as a conduit between user needs and the trade groups who actually carry out the tasks to meet these requirements. There are five categories of service that the SRC provides to the CMU community:

1. *Daily Service* (DS) is limited service work, scheduled by need priority and availability of trade groups. If one light is out in an office and alternative lighting is available, for example, the request is classified as DS.
2. *Unplanned Maintenance* (UP) is any emergency addressed within 24 hours to insure life safety, to protect university assets or to meet critical user needs. A report of total electrical shortage in a classroom is classified as UP on grounds of critical academic need.
3. *Planned Maintenance* (PM) is preventive maintenance carried out on a planned schedule to prolong equipment and building life cycle.
4. *Projects* (PR) include installation or modification work which enhances the asset value of a building and its systems.
5. *Parts/Contracts* (PC) is work pending due to material availability (longer than 1 week) and specialized services contracted to supplement service capability.

The primary tool of the SRC is the Service Order Scheduling (SOS) system. SOS system is used in generating, scheduling, and if required, estimating work orders. SOS system is also used to keep track of work in progress, backlogs, work completed, and work order history records. All work orders are currently recorded in a computer database. Monitoring and scheduling is done manually by the help of a scheduling board set up on a wall in the main SRC office. The board is a matrix of trade groups in columns and the five categories of response in rows. Actual work order forms are stacked on this board in the order they were received or as prioritized by the scheduler.

Preventive Maintenance at CMU

The steps taken in implementing the preventive maintenance (PM) program that was recently put in use at the Physical Plant include:

- selection of a pilot group of buildings for PM (twelve were selected initially),
- development of an equipment inventory for these buildings (where the equipment is located, what type of service is needed and whether it is a critical piece of equipment or not),
- procurement of the materials needed for PM,
- scheduling of activities,
- preparation of estimates,
- monitoring (developing a maintenance history, making future projections).

The equipment inventory is recorded in a computer database. Scheduling of activities, preparation of estimates and monitoring of PM activities are done manually. PM tasks.are usually planned over a twelve month period. While certain equipment requires monthly or annual maintenance, others require PM every so many years. Still, say that there are four pieces of a certain equipment on campus that need to be checked every four years. That means, one of these might be included in the PM schedule every year. The maintenance manager issues Maintenance Task Sheets for all types of equipment in the database. These sheets serve as punch-lists for the mechanics working at the site. The man-hours spent on a PM task can be tracked from these sheets. The maintenance manager has a record of estimated hours for specific tasks that he can compare against the actual time spent. This is one way of monitoring productivity. Every PM task on a sheet has an ID number that corresponds to a task description. These task descriptions are collected in a document to which the personnel can refer if needed. This helps in reducing the time and effort spent by the personnel in searching for answers to questions which may already have been answered. Currently, there are six people dedicated to PM.

Developing a maintenance history proves useful not only by providing the information needed to estimate when equipment is likely to require PM (other than its calendar age) but also by providing feedback to facilities designers and engineers for the selection of equipment previously used on campus. Such equipment previously employed by the University has a maintenance history on campus. A database of equipment histories should ideally lead to campus wide standardization in equipment selection.

User Operations: Space Management

The University Planning Office is involved in space management issues. Its tasks are grouped under two main categories: space inventorying and space analysis. For space inventories, the Planning Office uses a Facilities Management program running on the university wide Mirage system. This program is essentially a database created with *INGRESS* software. The space inventory database keeps track of space ownership, usage, and square footage and provides a variety of reports to departments in the University. The Design and Construction Office and the Office of the Registrar have on-line access to some of the database files.

The Planning Office also keeps space ownership drawings of all the buildings on campus. These drawings are created in a "paint" software package and are not linked to the inventory database These are not intelligent drawings. In addition to the University's own policies on space management, the Planning Office uses the *Physical Facilities Inventory System Instructional Manual* published by the Commonwealth of Pennsylvania and the *Revised Higher Education Facilities Inventory and Classification Manual* published by the National Center for Education Statistics as reference documents. The Planning Office also provides services in space analysis by giving feedback to departments on alternative space assignment scenarios. These scenarios are created manually.

Summary of Observations and Opportunities

Below, is a summary of our observations on the current status of facilities design and management activities at CMU, and opportunities for the development of an integrated database. This is a preliminary list which will be expanded in the future phases of our project.

- While bench marking the existing facilities design and management activities at CMU, we adopted the Woods Hole diagram into the one shown in Figure 3.6. When this diagram is compared to the original in Figure 3.1, one obvious difference to be noted is the distinctive separation between facilities design and facilities management activities at CMU. This separation is not present in the seamless schema of the Integrated Database. Furthermore, this presents problems of redundant data creation and discontinuous task follow-through.

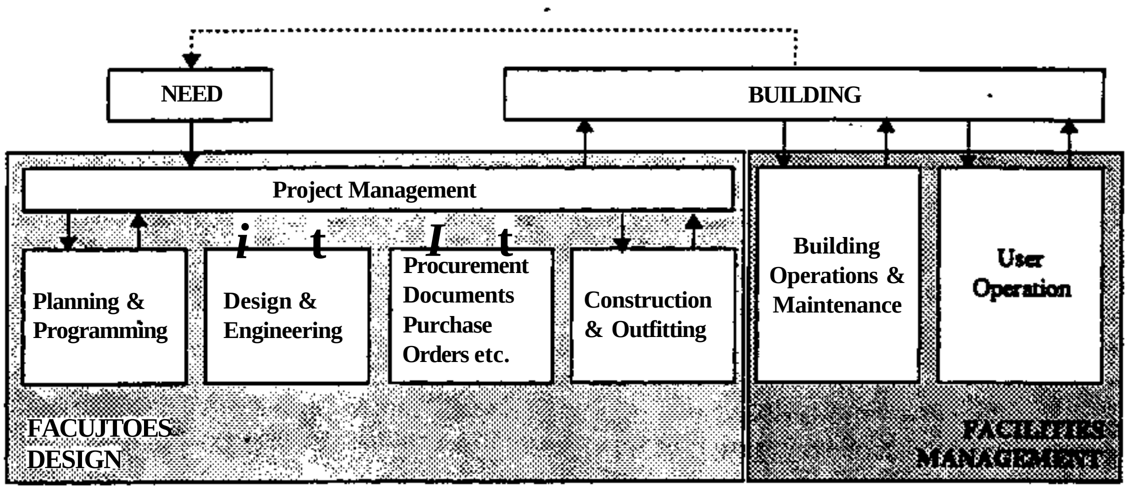

Figure *35* Facilities Design and Management at CMU.

- **Presently, computerized and manual methods are being used in an ad hoc manner in almost all phases of facilities design and management. A recurring trend is the use of computerized databases as a mere substitute for manual filing systems. For example, although there is an equipment inventory database, maintenance is monitored manually. Real advantages related to cost and time of operations are not realizable.**

- **In some cases, computerized methods themselves are being used discontinuously. There are "shaded" drawings of the buildings on campus in a paint program which depict space ownership. Independent of these graphical representations, there is also a space inventory database for these buildings. These drawings are not, however, usable by facilities designers working with computer aided drafting methods since they are raster images only and are not precise enough to convert into working drawings.**

The information presented in this chapter was gathered from interviews with Physical Plant and University Planning Office staff. However, if the University is viewed in its entirety (Hgure 3.7), it is possible to find other departments that might benefit from the Integrated Database. It would not be farfetched to claim that the data in the furniture inventory files of the Purchasing Department could be the same information used by the designers while renovating a classroom and the updated file for that space could be accessed by the Registrar in making decisions for classroom scheduling.

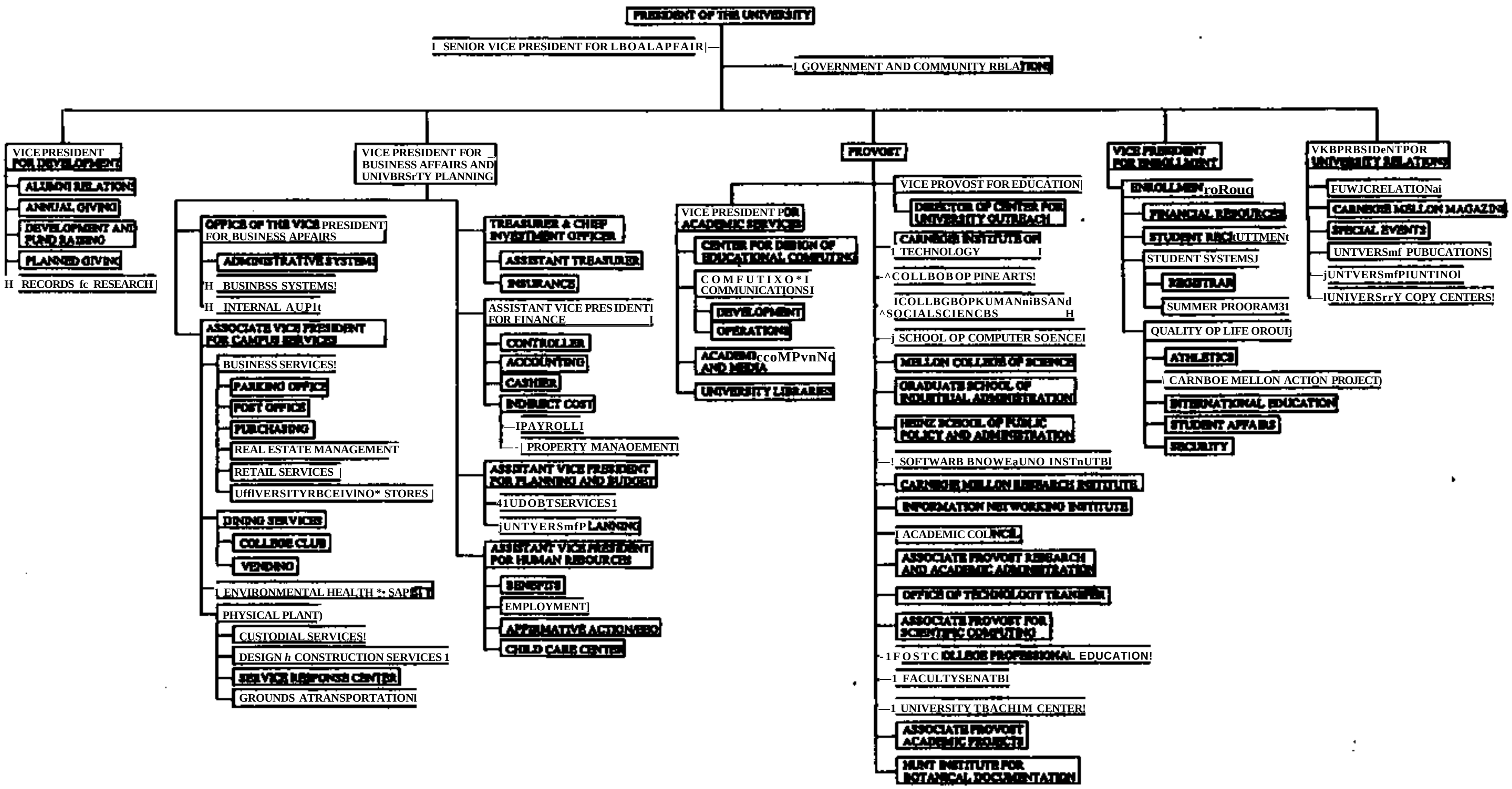

Figure 3.6 Carnegie Mellon University - Organizational Chart 1992

Acknowledgments

We gratefully thank Steve Saulis, Director of Physical Plant; Gary Robinson, Paul Tellers, Tom Murphy and James Secosky from the Design and Construction Office at Physical Plant; Steve Lyons and William "WEB" Brown from the Service Response Center at Physical Plant; Patrick Roach from the University Planning and Budget Office for the time they allocated for the interviews.

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Case Study Two

Change Orders and CAD

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What purpose a computer aided architectural design tool should serve has been discussed extensively. Still, researchers who have been working in developing "intelligent" tools to assist designers in their tasks are faced with the fact that "dumb" drafting packages dominate the use of computers in the architect's workplace (ALA, 1991). While the use of computers as drafting tools is increasing, it is claimed that architects are reluctant to use them in the "true" sense of the term: computer aided design. The explanation of this claim is more complicated than what is often given as designers' unwillingness to compromise their creativity. Traditionally, electronic drafting tools have been considered as a direct, one-to-one substitute for manual drafting, an unavoidable part of the design process. The benefits of computation in this case are easier to measure since the objective is to produce more accurate drawings in less time.

The integration of computer aided design tools over the whole span of the design process, on the other hand, is not an obvious task. Neither is it desirable nor is it efficient in the long run to look for a one-to-one mapping between existing processes and computer aided ones. Computer aided design tools are here to change the way things are done from the traditional modes of design activity, that is, if we are to realize any substantial benefits (Akin and Anadol, 1992).

There are a number of diverse issues related to the organization and human resources of the architect's workplace that the implementers of CAD tools need to consider together with the "dumb" *versus* "intelligent" characteristics of systems. These technical and non-technical issues have already been recognized in the implementation of new technologies in business, mechanical engineering, manufacturing (Forester 1989, Long 1987, Mumford 1983, Robertson 1992). In this study, we set out to identify methods to successfully integrate computer aided design tools such that there is measurable benefit to the practice. The work presented in this chapter is a bench marking study for comparing manual and automated projects to identify if and at what stage computer aided design tools have an impact on the building delivery process. If there is evidence that computer aided design tools have in fact made a contribution, the next step is to look at the way those tools have been integrated in the workplace. This work also involves the development of a method for undertaking this task.

Previous Work on Change Orders

A report prepared by the Committee on Construction Change Orders (1986), formed upon request from the agencies that sponsor the Federal Construction Council, explains that federal agencies have been receiving criticism from Congress and other government officials for excessive changes to their construction contracts. This has led the agencies to impose strict and costly controls on the changes they make which in some cases have jeopardized the functional performance of the new buildings. The committee has analyzed how the agencies record and report the changes and have made recommendations on adopting uniform standards. As a minimum, the agencies have been advised to develop statistics, on the basis of completed projects, on the number, dollar amount and percentage of original contract amount of modifications to their construction contracts and the reasons causing the change orders. The committee has advised the use of five broad categories of reasons in preparing the statistics: *design deficiencies, criteria changes, unforeseen conditions, changes in. scope* and *other.* The statistics provided for this study by two of the federal agencies show that changes related to *design deficiencies* are the most frequent and most costly among the five categories. Although the objective of this study is different than ours, the statistics reqtúrements, the categorization of changes proposed by the committee and the results of statistics analyses are similar to the ones with which we worked in this study.

Golish (1992) is presently working on another project to "analyze and categorize current Corps of Engineer projects to determine where most errors occur in the design/documentation process[11] and also to "determine to what extent automation ... and standardization ... have reduced errors in the process." His method involves analyzing and categorizing reviews and comments given to a number of Corps projects and then reviewing these projects after construction "to determine other errors missed by reviewers which result in change orders." He has broken down the types of problems to which reviewers point out in projects into three main categories: *criteria, design issues and documentation. Design issues are further broken down to scope, design analysis, design configuration, product/system selection* and *coordination.* Documentation related problems are also further classified into *coordination, omissions/errors, format/presentation of information, terminology* and *estimates.* It is worthwhile to note that, some of what Golish has categorized as problems encountered prior to construction, we have in fact observed manifested during the construction phase in the form of change orders.

Ibbs et. al. (1986) have studied the impact of various contract clauses on project performance. Examining the "change family" of clauses in contracts, they have listed fifteen types: *work scope definition, design changes, construction changes, quantity variations, workmanship variations, schedule intervention, errors and omissions, as-built drawings, correction of damage/other's work, subsurface investigation,* force majeure, *unforeseen conditions, design rework, equipment/material rework, construction rework.* Among these reasons of change, they have named work scope definition, design changes, construction changes, workmanship variations and design rework as the "most problematic" contract clause types with regards to the general measures of project performance such as cost, schedule, safety and quality. Among these measures, we have observed that the impact of changes on cost leads to similar observations.

Objectives

This paper aims to:

- determine the overall percentage increase in the contract amount due to change orders,
- categorize the reasons for changes,
- identify how many in each category of change exists,
- identify the impact of these categories of changes on overall increase in cost, and
- observe the implications present in the statistics for manual and automated projects.

We are interested in comparing two groups of projects, CAD *versus* manual ones, on the basis of the change order statistics derived from our observations. We are looking for any evidence which shows that there is in fact a difference between the two groups. We expect that use of computer aided design tools leads to see less number of changes and less increase in cost. In this respect, we will especially be scrutinizing those categories of changes that can be traced back to the design phase of the project.

Method

The study was conducted in two main steps: data acquisition and data analysis. The data acquisition phase involved the selection of offices, selection of projects, examination of written project records and interviews with the project managers of the selected projects. There were two offices involved in our study. One was the design and construction office at the physical plant of a private university and the other was a private architectural office. Throughout the paper, the former is referred to as "Office-A" and the latter is referred to as "Office-B." We have chosen these two particular offices primarily because they represent the two different categories of design delivery methods: Office-A predominantly uses manual methods and Office-B works with computer aided design tools. We should add that both offices were very cooperative in making their resources accessible for the collection of data.

The selection of projects was primarily driven by the intention to sample the two different categories. The second important criteria was that all projects we study would be completed projects, their written records would be filed and accessible. Both Office-A and Office-B projects were renovation jobs, completed in a "compressed construction time frame." This was not a premeditated choice on our part but did provide uniform grounds for comparison.

The examination of written project records involved the examination of the budget breakdown and most importantly the change orders issued for each project. We focused on the change orders issued to the general contractor. In each case, the final amount of the contract signed with the general contractor reflected more than half of the project's budget while the contracts signed with the subcontractors provided little or no information on changes. Since a change order often consists of a number of items, when looking at the type, number and cost of changes, we took these individual items into consideration rather than the change order documents, in lump sum.

Next, we consulted the project managers of each project to find out about the reasons for the change order items. Through these interviews, we developed eight categories for the reasons of change:

- The category of *incomplete as-built drawings* refers to the changes caused by inadequate or missing information because the as-built drawings of the building were incomplete.

- The category of *design errors* refers to errors of omission, errors of commission and the combination of the two made by the designers during the design phase of the project. There are yet other subcategories these three can be broken down into but within the scope of this study, we will only be referring to the main *design errors* category.

- The third category, *site conditions,* refers to the unforeseen conditions that were discovered during construction. This is distinct from the "as-built" category as it involves aspects of use and equipment installations not normally included in as-built drawings.

- The fourth category, *user requests,* are mainly changes in the scope of work requested by the user of the building or space that was being constructed. This category includes the cases where the user makes a change in his decision about the scope of the work or requests some part of the design to be demolished and reconstructed.[1]

- *Changes in scope,* is the collection of changes that were often initiated by the project manager. Such changes include repairing the damage done by others, extra work needed in anticipation of future additions, and improvements of performance of the facilities.

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[1] We separated this from the next category, changes in scope, since this is initiated by the user/owners of the space and not by the construction managers.

• *Contingency*, refers to anticipated additional work and for which necessary funds were allocated at the time the contract was prepared.

• The seventh category, *credits*, refers to the deductions in the contract amount due to elimination of work or savings realized through existing resources and value engineering.

• Finally, the eighth category, *combination*, refers to the reasons for change in which a combination of any of the seven categories mentioned above are relevant.

In the data analysis phase, we developed summary tables for the data collected and made observations on the trends present by the data. In the following section, we will discuss some of these findings.

Results and Observations

A total of eight manually delivered projects were examined from Office-A. The numbers of change order items issued to the general contractor for all projects totaled 196 and cost $250318 which represents a total original contract amount of $2,307,771 to a final $2,558,089 after the change orders. This means a 10.85 percent increase in the contract amount. The final total budget for these projects was $3,721344 representing additional appropriations made in each account once the initial construction phase was completed (Table 4.1).

Table 4.1; Office-A projects, statistical summary.

	590237	592108	590135	590124	590124	590129	591111	590129	TOTAL
Total Budget ($)	1,212,500	550,940	424,735	404,299	360,680	283,810	247,260	237,120	3,721344
Original Amount ($)	795,100	283,500	297,571	278,650	161,250	177,800	143,600	170300	2307,771
Numberof Changes	68	22	23	5	20	12	31	15	1%
Cost of Changes ($)	76,392	23,873	41,780	34,679	25,157	10,838	28,933	8,666	250318
Final Amount ($)	871,492	307,373	339,351	313329	186,407	188,638	172,533	178,966	2,558,089
Percentage Increase	9.61	8.42	14.04	12.45	15.60	6.10	20.15	5.09	10.85

There was only one project from Office-B and it was delivered using computer aided design tools. Fifty-nine change order items were issued, costing $240304. The original contract amount, $2,284,383, increased by 1052 percent to $2,524,687 (Table 4.2). Although several other projects were also available for our analysis none fit all of the selection criteria we used in this study.

Table 4.2: Office - B, Project 91200, statistical summary.

Original Amount ($)	**2,284383**
Number of Changes	**59**
Cost of Changes ($)	**240,304**
Final Amount ($)	**2,524,687**
Percentage Increase	**10.52**

Looking at the classes of reasons for change, in Office-A projects, the most frequent and most costly reason for change is the class of design errors. The second most frequent and costly reason isthe class of user requests. Third in this ordering is the dass of changes in scope (Table 4.3). •

Table 43: Number and coat of reasons for change in Of fice-A projects.

	as-built	d-errors	site	user	scope	[illegible]	credit	comb.*	TOTAL
Number	*53*	70.5	155	36.5	55	9	4	17	1%
Cost ($)	1,965	131,723	18438	36360	56^86	8,946	-4,500	50,907	250318
% in Total Increase	0.08	5.71	0.80	1.60	2.46	039	-0.19	N/A	10.85

* These are distributed between the classes from which they consist

This ordering changes in the Office-B project where the most frequent and the most costly reason for change is the class of user requests. The second most frequent and costly reason is the class of design errors. Third in the Office-B ordering is the class of unforeseen site conditions (Table 4.4). In a preliminary way this supports our hypothesis that the use of CAD may be responsible for the reduction of design errors, particularly when it is organized centrally and serves as a clearinghouse for design information generated concurrently.

Table 4 Number and cost of reasons for change in Office-B projects.

	as-built	d-errors	site	user	scope	contin.	credit	comb.*	TOTAL
Number	0	23.2	103	245	1	0	0	2	59
Cost ($)	0	87,478	35,104	95,658	22,064	0	0	21,873	240304
% in Total Increase	0.00	3.83	154	4.19	0.96	0.00	0.00	N/A	1052

* These are distributed between the classes from which they consist

During the interviews with the project managers, we took note of the observations they had made on the nature of the changes to their projects. One comment Of fice-A project managers agreed on was that most of the time, the changes were due to either changes in scope or user requests. Changes due to design errors did not occur as often but they did tend to cost more. After classifying the changes to Office-A projects (Table 4.3), we observed that this informal conclusion held. The sum of the number of changes due to changes in scope and user requests (approximately 91 changes) was higher than those due to design errors (approximately 70 changes). On the other hand the sum of the cost of changes due to changes in scope and user requests had less impact on the total increase in contract amount (37 percent of the total increase) than the cost of changes due to design errors (53 percent of the total increase). The project manager of the Office-B project had stressed the fact that user requests and unforeseen site conditions were the predominant reasons for change both by number and cost. We observed that the total number and cost of changes caused by user requests and unforeseen conditions was in fact higher than those caused by design errors (Table 4.4).

Considering that all of these projects were renovation jobs and from the observations of the project managers, we were expecting those changes due to incomplete as-built drawings and unforeseen site conditions to be much higher than what is reflected in the data. However, this does not overrule the possibility that these two categories might be among the underlying reasons for some of the change order categories. In fact, for both offices (Table 4.3 and Table 4.4), the sum of the costs of incomplete as-built drawings, unforeseen site conditions and design errors had a higher impact on the total increase in contract amount (61 percent of the total increase for Office-A and 51 percent for Office-B) than the sum of the costs of user requests, increases in scope, contingencies and credits (39 percent of the total increase for Office-A and 49 percent for Office-B).

Based on the small sample of projects we studied, especially in Office-B, it is somewhat premature to make comparisons between manually delivered projects and those that incorporated computer aided design tools. It is still useful to mention the trends that are evident in the data. For example, although the sum of the costs of incomplete as-built drawings, unforeseen site conditions and design errors had a higher impact on the total increase in contract amount in both offices, the impact on Office-A projects (61 percent of the total increase) is higher than the impact on the Office-B project (51 percent of the total increase). To establish that this difference is an indication of the positive contribution of computer aided design tools, more detailed comparisons looking at the subclasses of changes are needed. For example, comparisons can be made on the basis of design errors due to concurrent engineering where different parties might be working on incompatible aspects of the same design. We observed that Office-B shared the computer files of the architectural base drawings with the engineers which eliminated replication of data and also enabled these parties to act on the same information, consistently.

Conclusions

It is no great revelation that advanced CAD tools should be integrated in the architect's workplace. To see the impact of computers in this process, there has to be an understanding of the design delivery processes and the design agents involved as well as the potential role computer aided design tools might play in all of this. The bench marking study represented by this paper is aimed at identifying if and at what stage CAD tools may have an impact on the building delivery process. While limited by the sample of data we collected — the preliminary results indicate that CAD tools even if dumb drafting systems, can make a difference in controlling the numbers of change orders issued, provided that the CAD systems serves as a clearinghouse for design information.

The ultimate goal of our study has been to analyze the ways computer ?led design tools are integrated into the workplace with respect to relevant technical, organizat:: nal and human resource issues. We hope to extend the preliminary findings in these directions, in the near future.

Acknowledgments

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Case Study Three

Space Allocation for the College of Fine Arts

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To study the process of space allocation, we looked at the example of Carnegie Mellon University (CMU)and in particular, the continuing process of space allocation within the College of Fine Arts (CFA). A principal goal of this study is to gain insight into the benefits of and strategies for automating this process, within the general context of computer aided facilities management (CAFM) applications.

The College is composed of five departments: Architecture, Art, Design, Drama, and Music, as well as several extra-departmental institutes and centers of study. While CFA as a whole is based in the College of Fine Arts building, many departments use space in other, often unsuitable, campus buildings. Additionally, the majority of a second building, Margaret Morrison Carnegie Hall (MMCH) continues to be gradually vacated by those departments external to CFA. The University envisions dedicating the vacated space to the CFA. The desire of some departments to recentralize, as well as the impending construction of a Center for the Arts facility to accommodate the Drama department, necessitated the rethinking of current space allocation.

An outside consultant, John Fisher, of John Sergio Fisher Associates of Tarzana, California, was called in to plan the realignment of current space allocations to reflect both new construction as well as the changed needs of the different departments and other CFA entities. To formulate the revised space allocations, the consultant used a process, roughly divided into the following stages: (1) data gathering, (2) intermediate space allocation and mapping, and (3) configuration testing. (Figure 5.1) These three stages need not be exclusive to the case of the College of Fine Arts. Indeed, the CFA example illustrates a logical path which might occur in other space allocation tasks.[1]

[1] We collected our own data about this process through an interview with John Fisher and documents he has provided for our use, including the final report submitted to CMU which is cited in our bibliography. We are grateful to Mr. Fisher for his help in this study.

Data Gathering

The first area of concern for space allocation is data gathering. Before proceeding, the "allocator" must have building drawings which are accurate. From these drawings, he must be able to derive area totals. This collection of plans and area data is often no easy task. In Carnegie Mellon's experience, there were no single, consistently updated drawings of either the College of Fine Arts or Margaret Morrison Carnegie Hall. Floor plans on file often did not reflect changes in interior partitions. Additionally, the University's Planning Office and the individual departments often had different square footage tallies for the same spaces. An equally acceptable alternative to deriving area totals from plans is to use previously compiled data already correlated with the building's drawings.

Data, however, cannot be relegated to information available from floor plans. Additionally, the allocator will need a host of other information specific to the allocation task at hand. For certain functions, it will be imperative to know such diverse information as room height, proximity to a loading dock, or availability of 220 V power connections. While the person allocating space can never be certain of all the necessary variables, he can provide for a large number of these concerns by interviewing the groups affected by the allocation. In CMU's case, this meant interviewing each of the five departments, the Office of the Dean of CFA, and other representatives for the University.

Step 1: Interviewing on the Departmental Level

As a university, Carnegie Mellon serves as a good model of an institutional hierarchy. In the university as in most businesses, a management structure exists where divisions (colleges in the example of a university) are broken down into departments which in turn may be broken down into working groups. More refined "wish lists" can be derived from interviewing each department or working group separately. To account for the changing structures of these departments, the space allocator is confronted with different levels of need. In the case of CMU, this was expressed in terms of three questions: (1) what does each department absolutely need at the present time? (2) what would each department prefer at the present time? and (3) what are the department's future plans?

The first area of concern when conducting an interview with an individual department is to find that department's minimum needs in terms of both square footage of each space required and parameters, adjacencies, or infrastructure associated with these spaces. To reallocate space vacated by the Drama Department's move from the College of Fine Arts and Margaret Morrison, Fisher first interviewed the five departments of the College. From these first interviews, Fisher derived what can be termed essential parameters. Commonly found on the lists of each department were room height, evacuation of hazardous materials, and visual access to the exterior. Other parameters reflected the diverse natures of the individual departments, from the Music Department's acoustical concerns to the Architecture Department's need to be located near a loading dock-

After locating each department's immediate concerns, the space planner must then ascertain secondary concerns. As opposed to "absolute necessities", these secondary concerns relate to what the departments would prefer if given the choice. For some, this might mean a desire to consolidate far-flung spaces into one building. CMU's Design Department saw consolidation of its spaces from three buildings into one as secondary to the primary concern of having adequate square footage. Additionally, the Design Department would prefer such amenities as movable partitions. Providing for any similar "extras" can be considered as secondary to meeting the basic requirements of minimum square footage or room heights.

Finally, the space allocator needs to discern the future plans of the department in question. Going beyond an immediate "wish list", such plans for a University would include goals.which the department has to establish a graduate program or new research institute. There is a growing need to identify and anticipate the changing dynamics of the department in question. Adding additional personnel will directly affect space allocation. If the department knows it will be purchasing a ten foot tall piece of machinery, height considerations will affect future space allocation and must be accounted for. Technological shifts, notably the growing computerization of the workplace, must be anticipated when planning future space allocation. Will more spaces need to be dedicated as computer laboratories or data storage areas? While no one can be totally accurate in predicting the future, by carefully analyzing current trends and the future goals of each department, the space allocator can plan for many future developments.

Step 2: Interviewing above the Departmental Level

While individual departments, and specifically smaller working groups, can give the space allocator the most accurate idea of the specific needs of these groups, it is important for the space allocator to interview above the departmental level. In Carnegie Mellon's case, Fisher met with representatives of both the Dean of the College of Fine Arts and the administration of the school. Within the College, each of the five departments had a "claim" to certain areas, while the Dean's Office controlled other areas independent of the departments for its own administrative needs. Additionally, two research centers exist within the College which are controlled directly by the Office of the Dean and are independent of the departments.

Although the primary purpose of talking with the Dean's Office was to coordinate space allocation for the changing administrative needs of the office and of the independent research centers, an important secondary function was the use of the Dean's Office as a mediator for disputes arising at the departmental level. Representatives from the University's administration served the same function where the space in question belonged to a department external to the College of Fine Arts.

Data Gathering Phase: a template

With such diverse divisions as might be encountered in a university or corporate structure, it makes sense to explore streamlining the interviewing process for space allocation. As noted earlier, even the most diverse departments and working groups share basic concerns for space allocation. The value a department places on certain concerns is rarely shared to the same degree by other departments. Nonetheless, a standard questionnaire, format could be useful during the data gathering phase.

In his interviews with individual departments, Fisher gathered information on each space to be allocated by using a general outline, divided into conceptual, functional, and environmental control system requirements. He further subdivided the environmental requirements into acoustical, thermal, and lighting/electrical. While this method provided the results Fisher needed to perform the space allocation, it gave equal weight to all concerns for each department. Some departments considered conversational privacy to be the only important acoustical concern, where as a department such as Music described much more specific needs for acoustic separation, reverberation time, and wall surface texture.

To anticipate all needs of each department as related to space allocation is a difficult task. Therefore, we envision the creation of an automated "template" to anticipate and record the needs of any function group in an allocation task. Such a template might consist of a program which would interact with standard database files. Based on certain responses, the program could

search the data base for default values, obviating the need for the user to fill in each variable. One obvious benefit of such a system is that the template could be used both to collect information on a space to be allocated as well as to search the database for any rooms which fulfill the needs of the user. Additionally, the template might serve as a checklist for local and governmental safety ordinances. The system could, for example, then be used to identify emergency egress areas or spaces unsuitable for the storage of hazardous materials. It might even be able to adapt to changes that may be made in safety ordinances over the lifetime of the building.

A typical template would include, first, information on the room to be allocated and would include the room name, group name, department name, number of the space, and desired area. All additional information could be grouped into three categories: *adjacencies and proximities, interiors,* and *systems.* The first category, adjacencies and proximities, would contain questions about all links of the space, both physical and visual to other spaces. The second category, interiors, would contain questions relating to the space itself: its dimensions or proportions, and any material selections for the room's component parts. The third category, systems, would contain all questions related to environmental control with the space.

With such a template as outlined above, both data gathering and subsequently intermediate space allocation and mapping, could be automated and improved. Rather than providing the entire blank template for each and every space allocation task on campus, more detailed questions could be "triggered" by previous answers. Separate questionnaires could be created which would ask only those questions relevant to certain types of space. Answers to these questions, entered automatically into a database, would provide easily queriable data for more and faster intermediate space allocations.

Three possible examples of an allocation template are shown in Figure 5.2. The users are first presented with a set of five "space identification" questions. After these, the users can choose to use default fields to proceed with the process of data entry. If "yes" is selected, the system finds the most appropriate template in the database based on the answers to the previous five questions. In the left column of Figure 5.2, the responses "music," "graduate," "practice room," and "10" prompt a set of questions (in the left column) as well as their answers (in the right column.) Should users choose not to employ the default questions, they will type "no" at the "use default fields" prompt and will receive an all-inclusive version of the templates, not specific to their responses to the "space identification" questions. Again, to facilitate data entry, default answers are supplied in the full questionnaire based on the users[1] input of these first five questions. The users can alternately override any of the default questions or even the selection of the specialized template. The links between the initial questions and template types can, of course, be customized to each use situation.

Intermediate Space Allocation and Mapping

From information obtained in the data gathering phase, the space planner typically forms a series of intermediate space allocations, each time widening the scope of variables considered in the allocation process. In the College of Fine Arts example, Fisher identified square footage as the primary variable in consideration. Before individual concerns of different departments could be considered, he had to make sure that there was enough gross square footage to satisfy minimum requirements stated by the departments. As the space available to allocate was less than that made available by the Drama Department's move to the new Center for the Arts building, Fisher made an initial space layout based primarily on square footage needs identified in interviews with the departments in question. While not taking into account all other information, Fisher kept in mind several important adjacencies identified by some departments as primary concerns. By prioritizing the net square footage over other needs, he could assemble several rough drafts, or working plans, to which he could add further constraints set forth by the departments concerned.

question	response
room name	practice room
group name	graduate
department name	music
number of space	6
desired area	10
Use default fields?	yes
adjacencies	
connections	
to exterior	
visual	yes
interiors	
ceiling height	12
proportions	0.75
walls	durable
non-parallel	yes
systems	
lighting	
fluorescent	no
natursl	yes
acoustics	
sound isolation	
adjoining space	yes
HVAC	yes

question	response
room name	woodshop
group name	undergraduate
department name	architecture
number of space	1
desired area	3320
Use default fields?	yes
adjacencies	
connections	
to exterior	
visual	yes
physical	yes
near load'g dock	yes
internal storage	yes
interiors	
ceiling height	12
proportions	0.75
floors	durable
systems	
lighting	
fluorescent	no
natural	yes
electrical	
circuiting	separate
emer. cut-off	yes
environmental	
haz. mat. evac.	yes
air filtration	yes
acoustics	
sound isolation	
adjoining space	yes
HVAC	yes

question	response
room name	wood shop
group name	undergraduate
department name	architecture
number of space	1
desired area	3320
Use default fields?	no
adjacencies	
connections	
to exterior	
visual	yes
physical	yes
...	
near load'g dock	yes
internal storage	yes
interiors	
ceiling height	12
proportions	0.75
floors	durable
...	
systems	
lighting	
fluorescent	no
natural	yes
electrical	
circuiting	separate
emer. cut-off	yes
environmental	
haz. mat. evac.	yes
air filtration	yes
...	
acoustics	
sound isolation	
adjoining space	yes
...	
HVAC	yes

Figure 5.2. An automated data entry/ space allocation template.

To validate the initial variations in plan layout, the allocator must ask if all desired rooms have indeed been allocated and further if the total desired square footage has been allocated. A record of room areas, at this intermediate space allocation stage, needs to exist in a database. Any graphic interface which might show plans of the buildings in question would serve only as a secondary means of conveying information. The possibility exists, however, that by using graphics in addition to tabular information, the space allocator may see ways to manipulate an allocation. For instance, from a graphic, the allocator might see the possibility to create a lecture hall by combining three smaller rooms, at same time adding square footage formerly occupied by walls to the lecture hall.

After the initial space allocation, the logical path is to proceed to the configuration testing phase by integrating the department's less immediate concerns (or preferences) and future plans to produce further iterations of the space mapping. However, there may be, as in the case of CMU, the problem of lack of square footage available to meet the primary needs expressed by the departments. Constrained in this manner, the space allocator might opt for more intricate manipulations of the available spaces. Mezzanines might be added in high spaces or rooms might be subdivided. Fine tuning an alternative to increase net square footage might require including space currently occupied by walls and hallways. In each manipulation, the space allocator must consider the cost to benefit ratio of the proposed change.

Configuration Testing

After arriving at a preliminary allocation, the planner must fine tune it. The ultimate space planning solution (or several solutions) will satisfy both the square footage requirements, as well as the adjacencies and as many other parameters as possible of those set forth by all concerned parties. In this phase, the space allocator is concerned with meeting such secondary concerns as adjacency, room acoustics, exterior access and ceiling height. If space permits, a department's future square footage needs can be addressed here. When testing any of these configurations, if any concerns remain unmet and pose a serious problem to any involved department, the allocator can return to the testing phase taking these new factors into consideration. After all secondary concerns have been tested and implemented, the allocator might consider what could be deemed "tertiary" concerns. Any non-critical "extras" whether additional rooms, square footage or other that a department had requested fall into this category. One more classroom or larger storage closets might fit here. Again, with these tertiary concerns, the process would return to the intermediate allocation phase.

Conflict Resolution

In the alternative solutions proposed, there may still be unresolved conflicts between different departments over the allocation of a preferred space. In this case, a cost/ benefit or existing infrastructure analysis might resolve the conflict in favor of one solution or another. Such conflicts might be put in one of several categorized by physical concerns. For example, at Carnegie Mellon, both the Architecture and Design Departments wanted to consolidate their activities in the Margaret Morrison building. However, the sum of each Department's square footage needs exceeded the total available square footage in the building. Therefore, an intermediate space allocation could not accommodate both departments' desires. In this instance, other factors, in this case physical concerns, mitigated the impasse. The Architecture wood shop needed to have the high ceilings and access to a loading dock that Margaret Morrison could not offer. When the square footage of the wood shop was subtracted from the Architecture Department's total, the remaining needs of Architecture, added to those of Design, fit within the constraints of the building.

Additionally, conflicts might be resolved by comparing the existing and proposed functionalities of the given space. If Margaret Morrison offers existing office space, it might be more economical to continue to use this space for offices, rather than try to convert its use to studio space or other functions. Conflicts can further be resolved by considering adjacencies and contiguities of the space in question. Building on the above example, it would be desirable to place the Architecture shop next to the Freshman studios in the Margaret Morrison building. However, even if it were possible to build a loading dock in MMCH, placing the shop in CFA would offer similar centrality to all Architecture Department users.

Conclusions

As can be seen from the example of Carnegie Mellon, space allocation is largely a manual task, involving little or no use of automated computer tools. Many steps in the allocation process could be automated to provide improved efficiency and speed to the process. In the initial data collection stage, templates could serve as both a checklist for data to be entered and an automatic interface to the database. In this way, intermediate question forms could be eliminated, as the computer cold provide the template specific to different departmental needs. To decrease data entry further, default answers could be provided as indicated in Figure 5.2.

Automation could be used during the first, square footage based allocation. By using data records alone, without need to for graphic capability, the computer can easily compute area totals of required and available spaces. Beyond a simple area based allocation, an automated allocation system can use heuristic rules for conflict detection. By comparing records of the building's infrastructure with records of spaces to be allocated, the system can easily locate any and all rooms suitable for a certain purpose.

A more complex task for an automated allocation system is to find "new opportunities" not currently available in an allocation scheme. Such new opportunities might include the creation of one room where three had formerly stood. Removing walls is easily done by the computer; calculating the ensuing effects of structural and mechanical loadings, however, may not be. Thus the idea of integrating structural, mechanical, and other analysis programs to find "new opportunities" available in spatial permutations must be studied further for possible future application.

It is important to note that there are several tasks for which a manual approach to problem solving remains the most valid. While data entry can be automated, data collection both at and above the departmental levels need to be performed in an interview session, due to the unpredictable nature of these interactions. The automated template may indeed provide the best checklist of data to be recovered from the interview, but the interviewer can still function to record responses that even the automated template cannot anticipate. Also the space allocator, while testing the merits of alternative allocation scenarios, often needs to function as a diplomat to convince all parties involved of the merits of any given solution. This obviously is a process not conducive to automation.

It can be seen that the process of space allocation is multi-faceted, involving the distinct steps of data gathering, intermediate space allocation and mapping, and configuration testing. Diverse and often conflicting agendas which the space allocator must consider exist at several distinct organizational levels, from administration, to departments and working groups. With increasing demands on limited amounts of space, the space allocator is often forced to increasingly seek workable solutions for available space. In so doing, he encounters a large number of situations where conflict resolution must be called into play. By regularizing the diverse needs of all parties into standard templates used for both data gathering and intermediate space allocation and

mapping, the allocator has the potential to arrive at a wider array of feasible solutions in a shorter amount of time. Such an interactive system, if automated, may be able to search through a database for conflicts as well as solutions; and could become a standard tool for the space allocators, in the future.

References

Fisher, J. S. (1992) ***Carnegie Mellon University Center for the Arts, College of Fine Arts Consolidation,*** **Part II College of Fine Arts Consolidation Program, John Sergio Fisher Associates, Tarzana, CA.**