LESSONS LEARNED FROM MULTIPHASE RECONSTRUCTION PROJECT

By Raymond J. Krizek,[1] Member, ASCE, Wei Lo,[2] and Ahmad Hadavi,[3] Associate Member, ASCE

ABSTRACT: Because of the constraints of the existing building, a reconstruction project is more complicated and difficult than a new project, and a multiphase reconstruction project is even more complicated and difficult than a single-phase reconstruction project because of the additional constraints imposed by the owner to ensure the normal operation of the remaining portion of the building. In this study, the experiences gained during the first five phases of the multiphase reconstruction of the Technological Institute building on the Northwestern University campus in Evanston, Illinois, are examined through a review of the construction documents and interviews with representatives of virtually all the major parties involved in the project. The problems encountered are then analyzed within the framework of the contractual approach used and the experiences accumulated, primarily from the construction of new facilities, to deduce the variety of lessons learned. Chief among these lessons are: (1) The strong need for effective project management at all levels with continuous communication among all parties and the authority to render timely decisions; (2) the importance of a contract document that establishes a strong basis for handling uncertainties and changes that arise during construction; and (3) the special problems that stem from the multiphase reconstruction of a combined academic and research facility.

INTRODUCTION

Large buildings, roads, airports, and harbor facilities are primary candidates for multiphase reconstruction because: (1) The cost to reproduce them is generally much higher than the cost to reconstruct them; and (2) it is usually not possible to close the facilities to accommodate a single-phase reconstruction project. In a typical multiphase reconstruction project, only one section of a facility is reconstructed during any given period of time, while all other sections of the facility continue their normal function. As such, a multiphase reconstruction project has characteristics that are different from those encountered in the construction of a new facility. Among these characteristics are the vacation and reoccupation of the space; the need to continue functions of the organization with minimum interference while adjacent reconstruction activity is underway; the simultaneous negotiation and implementation of contracts covering various phases of the overall project; and the maintenance of communication and work flow with entities that have relocated.

NATURE OF RECONSTRUCTION PROJECTS

Construction projects are usually challenging because virtually every project is unique. Notwithstanding the similarity of experiences that are transferable from one job to another, the complexity of each individual project always renders it difficult to predict the outcome of the schedule, economics, and quality of construction with a high degree of confidence. This situation becomes increasingly complicated in the case of a reconstruction project due to a number of specific constraints that cause it to be much more unpredictable than a new project.

Physical Constraints

Existing conditions generally test the creativity and ingenuity of the designers because limited height and load conditions and the structure of the existing building often restrict the effective division of the space to satisfy the function required by the owner. New services must have adequate space for installation in the existing structure, and limited access to the site and shortage of space often impede the loading and stockpiling of materials. In addition, safety considerations dictate that construction activities must ensure the well-being of the individuals in adjacent portions of the existing structure.

Coordination Constraints

The contractor on a new project needs to schedule only those activities or tasks that are directly involved with the actual construction; in contrast, the contractor on a phased reconstruction project must coordinate reconstruction activities with the schedule of those who will continue to occupy and use the remaining portions of the building. Demolition activities are always disturbing tasks because they inevitably involve a high level of noise, dust, dirt, odor, and debris; however, they must usually be completed before the beginning of construction, while respecting the welfare and schedule of building occupants.

Utility Constraints

Disruption of utility service is an extremely sensitive issue in a reconstruction project; although considerable effort may be expended to avoid problems, the temporary interruption of mechanical and electrical service always causes inconvenience to the occupants. This situation is aggravated by the fact that utility work generally comprises a large part (often more than one-half) of the total construction activity and cost on a reconstruction project, and its complexity usually places it among the most difficult jobs in the entire project. Utilities are distributed to virtually every corner of each floor through connections to trunk lines, which extend vertically either from the basement to the top floor or vice versa, depending on where the equipment is installed. Therefore, any disruption in service on one floor may cause a problem on other floors; and the scheduling of connections to the existing utilities is particularly critical, especially for a building with research laboratories that are strongly dependent on continuous utility service.

Uncertainty Constraints

Because of the demolition work involved in a reconstruction project, the contractor is likely to encounter conditions that cannot reasonably be foreseen. Accordingly, plans prepared for

[1]Stanley F. Pepper Prof., Dept. of Civ. Engrg., Northwestern Univ., Evanston, IL 60208-3109.
[2]Grad. Student, Dept. of Civ. Engrg., Northwestern Univ., Evanston, IL.
[3]Adjunct Asst. Prof., Dept. of Civ. Engrg., Northwestern Univ., Evanston, IL 60208-3109.

Note. Discussion open until August 1, 1996. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 7, 1994. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 122, No. 1, March, 1996. ©ASCE, ISSN 0733-9364/96/0001-0044–0054/$4.00 + $.50 per page. Paper No. 7965.

J. Constr. Eng. Manage., 1996, 122(1): 44-54

the project often do not correspond with the existing conditions, because pertinent information (such as dimensions) is not available until demolition is in progress. Sometimes the design is in conflict with the existing conditions, but this can be verified only after the demolition; the more extensive the demolition work, the more difficult it will be to provide accurate information and the greater will be the need for the contractor and the owner to negotiate ''good-faith'' solutions to problems that arise.

OBJECTIVE

The objective of this study is to provide helpful insight to those involved in multiphase reconstruction projects by reviewing and examining the history of the first five phases (four of which are complete) of one particular project.

THE BUILDING

The building being reconstructed is the Technological Institute (Tech) of Northwestern University in Evanston, Illinois. The cornerstone of the Technological Institute was laid in May 1940 and the building was completed in June 1942. The original five-floor building had a core section and six wings (in the shape of two ''E''s laid back to back and joined by a central area) encompassing about 423,000 sq ft (39,300 m^2) of floor space; at the time of its completion, it was the largest building in the country dedicated to education and research. Two more wings [about 100,000 sq ft (9,290 m^2) of floor space] were added to the original building in 1962, and all or portions of three of the six spaces between the wings were developed in subsequent years. Fig. 1 shows the plan of the original building and the added portions. The building houses the administration offices, faculty offices, classrooms, teaching facilities, and research laboratories for engineering and several applied science departments (the legend in Fig. 1 refers to occupancy of the reconstructed building).

THE NEED

By the late 1980s, virtually all major systems in the building were antiquated and generally inadequate to support the demands of modern research. In particular, the electrical system was functioning at capacity; the plumbing system posed frequent problems; the sewer system often clogged; the heating system was incapable of adequately heating several offices and laboratories; the ventilation system was not sufficient for expelling hazardous gases and the fumes from occasional chemical spills; necessary safety and fire-prevention measures were not in place; and the building was not centrally air-conditioned. Over the years new research projects required new facilities, and these were obtained either by reallocating existing space or by creating new space; however, the reallocated or created space was often not completely adequate. In short, state-of-the-art research and educational laboratories that were ideal for yesterday's projects were outdated, inefficiently utilized, and grossly unsuitable for today's and tomorrow's projects; computer rooms did not satisfy specified conditions of temperature and humidity; and the growth of the various engineering departments was different from that anticipated several decades ago. These issues dictated the timely construction of a new building or the gross reconstruction of the existing one.

THE DECISION

The decision to reconstruct the existing building was based largely on economics. Apart from its historical significance and beautiful exterior walls (the Lanon stone with Bedford trim used on the exterior of the building relates it to other

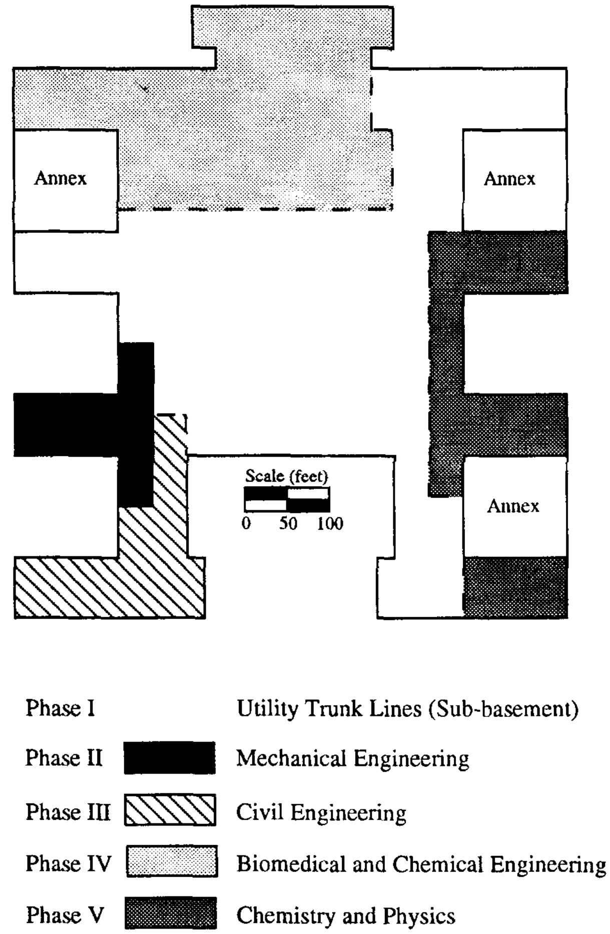


FIG. 1. Plan View of Technological Institute Building

university buildings in which this combination of materials has been used effectively, and the flat paving brick combined with stone in the spacious entrance court creates a pattern that brings a broad open space down to human scale), the cost of demolishing the existing building and constructing a new building with equal square footage would greatly exceed the cost of reconstruction. Alternatively, construction of a new building on a different site would still leave the challenge of modernizing the existing building and making it serviceable for another purpose. However, even if the demolition alternative were economically feasible, it would have been impossible to implement because neither space nor funds were available to relocate the extensive teaching and research functions in the building during the demolition and construction period. These considerations dictated the decision to undertake a multiphase reconstruction of the existing building.

THE PLAN

The basic plan was to reconstruct the existing building in phases, over a period of about eight years, to create a state-of-the-art environment for research and teaching in such a way that: (1) The overall project cost (including the cost of relocation and temporary service) would be minimized; and (2) each phase would be ready for the beginning of an academic year. Another part of the plan was to undertake any required demolition during the summer so as to minimize noise and disturbance while classes were in session. Accordingly, cost and time were the major criteria to be satisfied.

THE COMPLEXITY

An appreciation for the complexity of the Tech reconstruction project can be obtained from the diagram in Fig. 2. Eleven

J. Constr. Eng. Manage., 1996, 122(1): 44-54

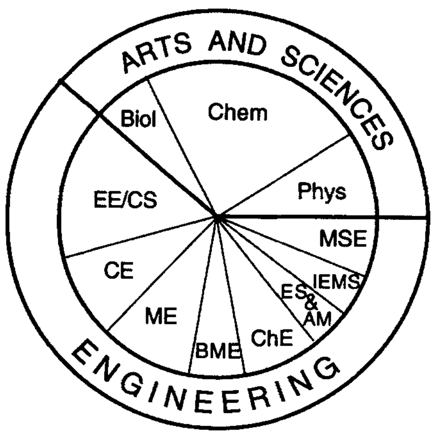


FIG. 2. Academic Units Involved in Tech Reconstruction

different departments and several research centers (which are, in effect, combinations of various department resources) from two different colleges are housed in the building, and each would be intimately affected by the reconstruction effort. Many departments would ultimately occupy space different from that currently occupied, and in some cases two or more moves will be necessary to make the transition. Faculty input was needed to develop customized floor plans for space utilization, while maintaining some semblance of overall uniformity in the finished building, and this task had to be accomplished by a faculty, which, albeit motivated and sincere, is generally inexperienced with this type of activity. Interaction and communication among faculty, administration, architect, designer, manager, and contractor was expected to present innumerable challenges to the patience of all, while approximately one wing per year undergoes reconstruction over the next eight years or so. And all of this had to be accomplished with as little disruption as possible to ongoing research and teaching activity, while simultaneously undertaking a fund-raising campaign to acquire the monies to proceed (a major grant provided the means to initiate the project and complete the first few phases, but the timely completion of the project depends on the continued raising of adequate funds).

THE VISION

Within the context of the foregoing framework, a group of faculty presented to the university administration a vision of how this unique $100,000,000 phased reconstruction project might be undertaken as an avant-garde full-scale "demonstration project" by utilizing, to full advantage, the plethora of modern technological tools that are becoming increasingly available through the advancement of computer hardware and software. In particular, the use of interactive computer graphics was advocated to develop the project from start to finish. In this case, however, "start" included the fund-raising stage, and "finish" encompassed the maintenance management. In a very real sense the implementation of this concept and the development of a computerized three-dimensional database would be useful in all stages of the project—not only in the initial development, space planning, and project coordination.

The synergism provided by the common computer graphics database is illustrated schematically in Fig. 3, which depicts the four major steps in the overall process. Explanatory information pertaining to each individual step (or lobe of the diagram) is divided into three parts. The top part indicates the primary task addressed, while the bottom part designates the unit or units with major responsibility for implementing the indicated task. The descriptors in the center portion of each lobe suggest some of the more pertinent tools provided by this approach to enable responsible units to better attain their objectives. As the reconstruction effort moved from fund-raising (step 1), planning and design (step 2), construction (step 3), and eventually facility management (step 4), the computer database entered at the beginning would be transferable and would simplify management of the entire project. The use of this concept would have represented one of the first complete applications of the integration of financing, planning, design, construction, and facility management functions.

Graphics Video for Fund-Raising (Step 1)

Initially, as indicated in step 1, the development office could have used interactive walk-throughs and flyovers to help their fund-raising efforts. Controlling this process via computer graphics could have provided the innovative distinction that is desired when conveying to technically oriented potential donors the excitement of reconstructing a building such as the Technological Institute. The suggested images for the fund-raising stage were: (1) A wire-frame flyover at the Northwestern campus; (2) a wire-frame walk-through of Tech; (3) a solid rendering of an example wing; and (4) a bidirectional database linking the floor plans of existing room use to the future uses of comparable space by each department.

Interactive Graphics for Design and Planning (Step 2)

Computer graphics depiction of existing and anticipated department space needs can help those not familiar with construction drawings to visualize the project as it will ultimately appear and, thereby, contribute more effectively to the process

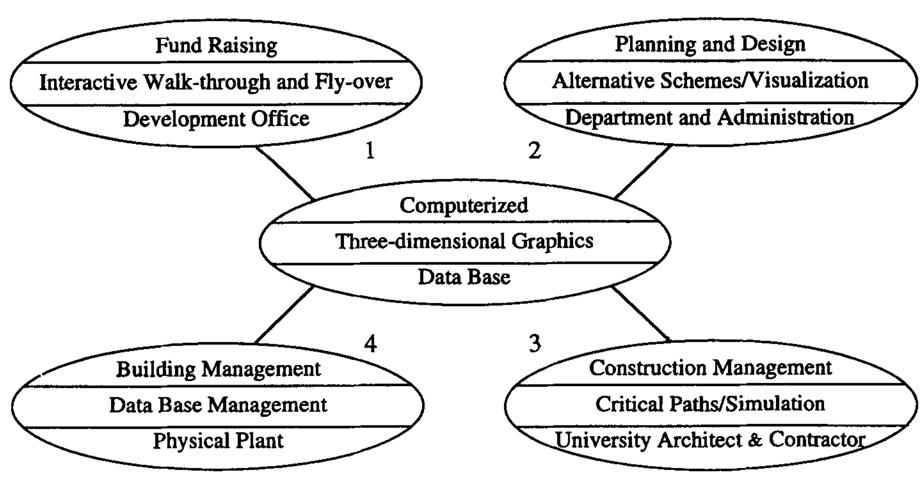


FIG. 3. Synergistic Uses of Common Computer Graphics Database

J. Constr. Eng. Manage., 1996, 122(1): 44-54

TABLE 1. Areas and Costs for Phases II–V

Phase (1)	Gross area (sq ft) (2)	Net area (sq ft) (3)	Construction cost only (dollars × 10^6) (4)	Cost per net sq ft (dollars) (5)
II	40,000 (3,716[a])	25,311 (2,351[a])	6.4	253 (3,723[b])
III	57,000 (5,295[a])	31,490 (2,926[a])	7.7	245 (2,632[b])
IV	138,000 (12,821[a])	67,000 (6,225[a])	13.6	203 (2,185[b])
V	108,000 (10,034[a])	65,000 (6,039[a])	23.2	357 (3,843[b])

[a]In square meters.
[b]Cost per net square meters.

of deciding where each department will ultimately be located, how it will get there during the reconstruction process, and the means by which experimental research can continue (if possible) during the turmoil. Interactive manipulation of "as is" and "to be" graphic space data via the bidirectional database link can allow "what ifs" to be rapidly investigated in real time and displayed visually. This type of visual approach to space planning and final design can eliminate many complaints that result from a poor understanding of the resulting geometry and interrelationships, and it can decrease the design cycle time required to reach a consensus. Further, changes can be instantly incorporated into the database, making it an up-to-the-minute model of the current situation.

Graphical Simulation of Construction (Step 3)

Graphics data can be employed in the construction-management phase of the project through the use of graphical construction simulation and bidirectional database links. As design parameters become more detailed, it would be possible to simulate construction sequences three-dimensionally in order to: (1) Reference materials needed for different areas; (2) evaluate how construction in one area affects another area; and (3) track construction progress. Such simulation of the construction process at an early stage in design can facilitate the selection of the least disruptive and most economic sequence of events. For example, a model can be disassembled and reassembled to investigate the possible occurrence of problems such as equipment access, conflicting storage and assembly area, and work space conflicts. After simulation, each modeled component can be assigned to an activity descriptor from which quantities can be determined; these quantities, when multiplied by installation rates, determine activity duration. Repeating this process for each activity can create a project schedule based on a verifiable planned construction sequence and actual design quantities.

Database Linkage for Facility Maintenance (Step 4)

The last step, facility management, can combine the detailed end-of-construction locations of electric, water, gas, and air lines; air-conditioning ducts; and other important facilities with the bidirectionally linked database of the manufacturer, type of equipment, date of installation, specification, etc. Accordingly, all future maintenance can be done by using both the graphical and alphanumeric data. In an emergency situation, the graphics data can allow instantaneous tracing of power or water lines, determination of ease of access, and selection of repair parts. The same speed and ease of use can also apply to the more mundane aspects of facility management, such as the location phone lines for new offices and the installation of water, gas, and ventilation for new laboratories. Hence, this computer database can provide a dynamic up-to-date representation of the operating building in precise detail, which can be easily and speedily accessed for any need.

Action Taken

Although some aspects of this vision were implemented by the university administration, the overall plan was not accepted. The reasons for this decision stemmed from concerns that the cost would be excessive and the project would be slowed down; in addition, there seemed to be a general feeling that the approach advocated was not really necessary.

IMPLEMENTATION

In the early stages of the project, a Tech Reconstruction Committee (consisting of faculty members, administration representatives, and the university architect or his agents) was appointed to: (1) Make recommendations regarding general and interdepartmental issues pertaining to the project; (2) interview recommended design firms and contractors selected by the university architect (candidates were restricted to Chicago-based firms for the first four phases); and (3) choose a designer or contractor for submission to the administration. The committee solicited information from each department regarding its requirements within the framework of the space allocated to it by the administration. Each department worked in conjunction with a representative from the Office of the University Architect and an external consultant to prepare a program of requirements (POR) for the reconstruction of its allocated space; this plan was scrutinized by the Reconstruction Committee to ensure compliance with established guidelines and then sent to the administration for approval. Actions of the Reconstruction Committee consisted of recommendations only; all decisions were made by the administration or the university architect. The university architect was the legal representative of the university and was responsible for inspecting the work and approving the payments.

Summary of Costs

Table 1 shows the areas and costs for phases II–V. By way of explanation for the substantial difference in cost per net square foot in some cases, the following overview is provided. The nature of the work in phases II and III was very similar. In contrast, the portion of the building reconstructed in phase IV was more than 20 years newer than those portions in phases II and III, and many of the existing walls were saved. Phase V, on the other hand, included much more extensive plumbing and air-handling facilities (e.g., more than 200 hoods) to accommodate the departments of chemistry and physics.

Phase I

In the initial phase of this project, asbestos was removed from the pipes in the subbasement and new power-supply trunk lines were installed. As the phased reconstruction proceeds, individual department power systems will be connected to these trunk lines. This work entailed little disruption to the normal teaching and research activities in the building and few occupants even realized it was being done. This phase of the

J. Constr. Eng. Manage., 1996, 122(1): 44-54

overall project does not form part of the primary experiences utilized in assessing the lessons learned.

Phase II

The mechanical engineering wing, consisting of approximately 25,311 net sq ft (2,351 m^2), was the first section of the building to be reconstructed. Following the development and approval of its POR, three major Chicago-area design firms selected by the university architect were interviewed by the Reconstruction Committee and one was subsequently chosen by the administration. Due to an untimely start of this phase, the traditional design-construct process would have taken several months to implement and thereby delay the start and completion of the reconstruction for a whole year because the relocations (both the initial move out of the existing space and the subsequent move back into the reconstructed space) would each have to be accomplished during the summer months, before the start of each respective academic year. Therefore, it was decided to use a construction-management system for this phase, and to begin the construction work while proceeding with the design. Three construction-management firms selected by the university architect were interviewed by the Reconstruction Committee and the recommended one was approved by the administration. Work began in September 1990 and was completed on time in August 1991.

Phase III

The civil engineering wing, consisting of approximately 31,490 net sq ft (2,926 m^2), was the second section of the building to be reconstructed. Since the nature of this reconstruction was very similar to that in the mechanical engineering wing, the same designer was retained. However, despite the satisfactory performance of the phase II construction manager, the same decision was not made for the construction work. In this case the design documents were ready in a timely manner and the administration wanted to benefit from the prevalent down-market in the construction industry. Hence, the decision was made to use the general contractor approach instead of a construction manager, and several prequalified general contractors (one of which was the phase II construction manager) selected by the university architect were invited to submit fixed-price lump-sum bids; accordingly, no interviews were conducted and the selection criterion was simply the lowest bid. Work began in September 1991 and the space was reoccupied in September 1992, more than two months later than planned. Although the data in Table 1 indicate a small (about 3%) savings in the cost per net square foot between phases II and III, it is believed that these savings are primarily attributable to the down-market and not the choice of contractual arrangement; because the subcontractors were also affected by the same down-market, it is possible that the savings would have been greater under a construction-management approach.

Phase IV

The work plan for the reconstruction of this 67,000 net sq ft (6,225 m^2) phase of the project, which houses the receiving facility, biomedical engineering, chemical engineering, and significant portions of chemistry, was considerably different from those for phases II and III; this is because the space to be reconstructed was in the newer portion of the building and many of the existing walls and facilities were to be retained. The administration decided to retain a different designer (one of the contenders in phase II, chosen in this case by negotiation) for this phase and to continue with the general contractor lump-sum bid approach (but the general contractor who did phase III was deleted from the list of prequalified bidders). Work was started in September 1992 and was scheduled for completion in July 1993; however, the project was delayed for several months and the space was not occupied until January 1994.

Phase V

The primary occupant of the 65,000 net sq ft (6,039 m^2) phase V space is the Department of Chemistry and a secondary occupant is the Department of Physics. The chemistry faculty, a strong academic group in the university, conducted a diligent study to identify a highly qualified and experienced design firm specializing in chemistry laboratory development, and they were successful in convincing the administration and the university architect to retain this firm, notwithstanding the fact that they are an out-of-town company. The general contracting method is being used for this construction, which began in April 1994.

Remaining Phases

At this time there is no definite schedule for completing the remaining phases of the project. Continuing efforts are being made to raise additional funds to complete the work, but reconstruction activity will be suspended in the event that sufficient funds are not available in a timely manner.

GENERAL ISSUES

As discussed earlier, the inherent nature of a multiphase reconstruction project dictates that work will be strongly influenced by a number of general issues that are not normally so dominant for a new construction project. Following are summaries of several general issues that were considered to be especially influential on this project.

- The existing building provides a multitude of constraints to the reconstruction project, and the details of these constraints must be well-known and fully understood before proceeding with the design.
- The mechanical, plumbing, and electrical systems have many special requirements and are the main components that control the schedule.
- Many aspects of the work are indeterminate at the outset, and there will probably be many inconsistencies between drawings and reality.
- There is limited access and working space, and there are many restrictions to the work sequence and the time to perform certain activities.
- The laboratories must be well equipped with a variety of services and designed to be flexible.
- A greater than normal number of parties is involved, and effective communication and interaction among all parties is especially important.
- The variety of potential problems that may be encountered dictates that there must be a high degree of flexibility and the ability to make decisions in a timely manner.
- Weather is a key factor to when scheduling the installation and operational shakedown of the heating, ventilating, and air-conditioning (HVAC) system.
- More workers (relative to the number needed for new construction) will probably be needed to maintain the job schedule, especially at the end.

PERSPECTIVES OF PARTIES INVOLVED

To obtain a perspective of the problems encountered or perceived during the first five phases (primarily phases II, III, and IV because phase I is not included and phase V is in the design

J. Constr. Eng. Manage., 1996, 122(1): 44-54

TABLE 2. Titles and General Affiliation of Interviewees

Owner (1)	Designers (2)	Contractors (3)
Associate provost	Associate partner, phases II and III design firm	Vice president, phase II contractor
Chairman, Department of Civil Engineering	Architect, phases II and III design firm	Project manager, phase II contractor
Chairman, Department of Mechanical Engineering	Vice president, phase IV design firm	Project coordinator, phase III contractor
Architect, Office of University Architect	Vice president, phase IV design firm	Project manager, phase IV contractor
Director of Laboratories and Facilities, Department of Chemistry	Architect, phase IV design firm	—
Faculty Representative, Department of Biomedical Engineering	—	—

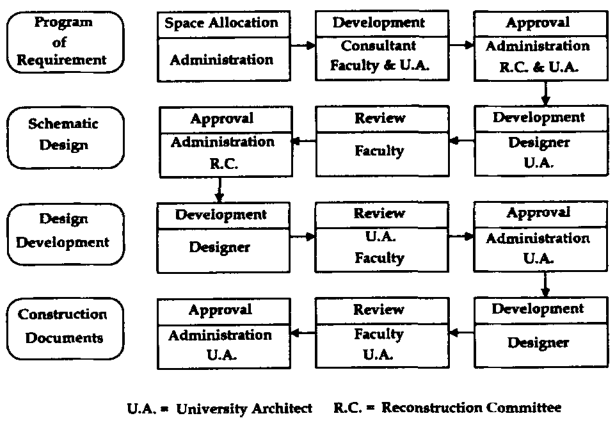


FIG. 4. Flow of Information during Design Stage

process) of this multiphase reconstruction project, representatives of most of the entities associated with the work were interviewed at length. The titles and general affiliation of interviewees are shown in Table 2.

During each interview, the interviewee identified conditions that were deemed problematic and contributory to the ineffective accomplishment and/or delay of the work. In addition, general issues of concern, potential sources of trouble, and expectations from other parties to the contract were discussed. This information is summarized in the following sections, and then synthesized and analyzed within the framework of an idealized project to determine lessons that might be learned and recommendations that might enhance performance on similar projects. Following are the real or perceived problems encountered by various participants during the course of this work; the problems stated were not necessarily voiced by all representatives in a given category.

Problems Raised by Faculty

- Both designers lacked experience in designing a building to accommodate both educational facilities and complex laboratories for scientific research; in addition, the designers lacked build-out experience.
- The designer and the contractor both exhibited uncooperative attitudes at times.
- The on-site representative of the university architect had limited authority and was not readily available much of the time.
- Insufficient inspection of the work led to poor performance and quality.
- Phases III and IV were not completed on time, causing chaos by the inability to reoccupy the space according to the original schedule.

Problems Raised by University Architect

- There were too many changes by the faculty too late in the process.
- There were too many missing or incomplete drawings.
- The contractor and the designer were both inexperienced.
- The contractor was behind schedule and often provided no schedule.

Problems Raised by Designers

- Too many University entities (Reconstruction Committee, faculty, administrators, and university architect) were involved in the "chain of communication."
- Changes in the requirements were frequently requested by the faculty.
- Faculty had little respect for the architectural point of view.
- The design constraints of the existing structure and the limitations imposed by the university was very severe.

Problems Raised by Contractors

- Drawings were incomplete and contained insufficient information.
- There were too many change orders.
- No single representative was readily available and fully authorized to make decisions on a timely basis.
- It was frequently necessary to notify the university of impending activities.
- The university was slow to respond with solutions to problems.
- There were too many physical constraints.
- The time allocated to complete the work was inadequate.

ANALYSIS

The problems encountered are analyzed here within the context of the general issues that were reasonably anticipated at the outset of the work and the decisions made by the university at various points in the process to respond to these issues and concerns. Most of the university decisions of interest relate to the contractual approach, the choice of designer and contractor, and the steps taken to control the process and quality of the work. Interspersed throughout the project are a multitude of communication difficulties and problems related to the lines of authority and timeliness in the use of this authority.

Chain of Communication and Authority at University

As mentioned, there are four major entities within the university involved in the design. Due to the unclear distinction of the authority and the lines of communication among each entity, many unnecessary problems occurred; sometimes the faculty blamed the designer for an uncooperative attitude, while the designer felt a sense of disrespect from the faculty. Fig. 4 shows the flow of information and the decision-making process during the design stage. Although the faculty have the responsibility to formulate the plan for effective utilization of their space, they have little to no authority to make the final decisions. Frequently, the opinions and changes suggested by the faculty resulted in cost increases or trade-offs between two different objectives, such as appearance and function, but the final decisions on these matters were made by the administrators and the university architect without consulting the faculty.

J. Constr. Eng. Manage., 1996, 122(1): 44-54

Thus, many misunderstandings occurred between faculty and designer. In essence, the designer was in a difficult position because, notwithstanding any desire to address a faculty concern directly, the university architect was the sole representative of the university and the only one fully authorized to decide on issues concerning the project.

Selection of Designers

Since both the university (as represented by the faculty, administration, and university architect) and contractor complained about many problems related to the quality and completeness of the design drawings, it is logical to question the competence of the designers. When evaluating the competence of a designer, two criteria must be considered: (1) The competence of the firm, as evidenced by the accumulated experiences of the firm based on previous projects; and (2) the competence of the individuals who are assigned to handle the details of a given project. Although the overall corporate competence is used primarily as a screening device to select potential design firms, the success of the project is ultimately determined to a large degree by the competence of the individuals assigned to the project. Both these criteria were considered in the selection of the designer for each phase, but the selection process often involves intangible considerations, which are weighted at the discretion of the administration. Although there was limited opportunity for the faculty and Reconstruction Committee to suggest design firms, the candidate firms were (for all practical purposes) selected by the university architect, who also imposed the restriction that only Chicago-based firms were accepted. The phase V designer was an exception to this pattern, and the faculty, based on the experience gathered during the earlier phases, played a dominant role in this selection. Thus, three different designers worked on phases II–V.

Selection of Contractors

A contractor is essentially a manager of materials, money, equipment, man power, and time; if there are deviations from the original plan in any of these five components, the construction product will be impacted. Accordingly, the owner should select a contractor in whom he has complete confidence. For most major projects, contractors are evaluated either pretender or posttender, and sometimes both.

Pretender

Prior to allowing candidate contractors to participate in a project bid, an evaluation of their qualifications (such as reputation, past performance, experience record, current workload, financial stability, equipment, and technical expertise) should be performed. Once such a prequalification is made, cost becomes virtually the only criterion by which to select one over the other. This approach is satisfactory provided there is truly no reason to prefer any one contractor on the prequalified list; if there is reason to prefer one specific contractor, a negotiated contract should be considered.

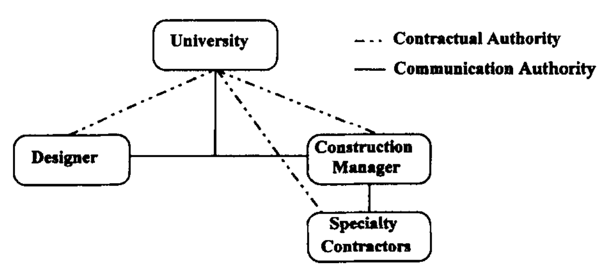
Posttender

Bidders are often required to submit a technical proposal together with the bid price. This technical proposal usually includes a master schedule, equipment and man-power schedules, and a statement of the construction method that will be used to perform the work. In addition, most tenders include resumes of the key personnel who will be assigned to the project.

In the current situation, no information was available to the faculty or the Reconstruction Committee to determine how the prequalification parameters were established, how the posttender evaluation was conducted, or how the final decision was made. There was no faculty input into the selection process, and the lowest bid was apparently the major criterion influencing the selection of a contractor for phases III and IV. As anticipated at the outset of the work on phase III of the project and as history subsequently verified, the selection process was apparently the root cause of most problems experienced during this phase. There was evidence in the early weeks of construction to indicate that the contractor was not fully aware of all responsibilities described in the contract, and the progress of work in the ensuing weeks was fraught with a wide assortment of problems and misunderstandings. The work continually fell behind schedule and ultimately the contractor left the job several months late without completing it; after one year, another contractor had to be retained to complete the unfinished work (punch list). Phase IV was also several months late and plagued with its own series of complications. Three different contractors worked on phases II, III, and IV.

Contractual Approach

The university chose different approaches to the design and construction of phases II, III, and IV. For one phase a construction-management firm was employed, and, from the beginning of the design work for this phase, this manager helped the university plan, administrate, and control the overall construction effort in a manner best suited to the university's objectives. The relationship of the various entities in this type of approach is illustrated in Fig. 5. In this case the university received the benefits of minimum design-construct time, compliance with recognized administrative and control requirements, and assurance of quality and utility in the finished product. The project progressed smoothly and was completed within the required time period. There were relatively few complaints and unpleasant events during the construction period, and the construction manager was responsive to several minor modifications to the work plan without undue formality. However, this approach was not used in the other two phases, because it was believed that the university could benefit from the prevalent down-market in the construction industry by using a competitive bid approach. Accordingly, for each of these two phases the university selected a general contractor by competitive bid from a group of prequalified contractors; once the prequalification was established, price was essentially the only distinguishing factor. The two contractors won their jobs

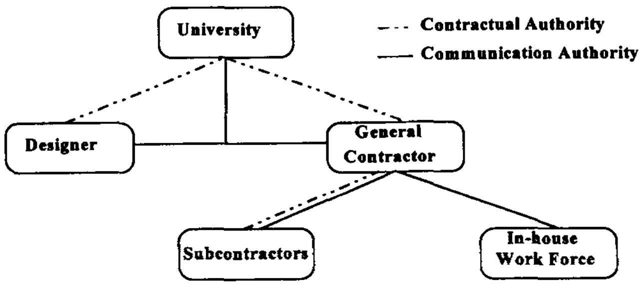


Features:

- Three-party team of owner, designer and construction manager
- Fixed price construction contracts directly with owner
- Some Specialty contractors were units within construction management firm
- Construction manager acts as owner's agent to extent delegated
- Negotiated professional fee for design and construction management services

FIG. 5. Relationships in Construction-Management Approach

J. Constr. Eng. Manage., 1996, 122(1): 44-54



Features:

- Single general contractor
- Fixed price construction contract
- Many subcontractors

FIG. 6. Relationships in Competitive-Bid Approach

by slightly less than 2%. The relationship among the entities involved in this type of contractual arrangement is illustrated in Fig. 6.

Construction Management versus Competitive Bid

On this project the management of the two phases contracted via competitive bid was not as effective as that in the phase handled with a construction manager, because the two general contractors did not function as a construction manager (of course, there was no requirement to do so). Likewise, the university architect did not serve this function (nor was there any plan to do so). Accordingly, whenever there was a problem on site, the contractor contacted the designer directly instead of first consulting with the university architect. In one of these two phases, the contractor complained about the interference of the faculty member representing the department that was to occupy the space. According to the contractor, this interference caused considerable confusion in the execution of the work, whereas the intent of the faculty member was simply to ascertain that the project was being constructed to fulfill the department's needs (this problem stems from the fact that the faculty is the actual user of the space, but not a contractual partner in the process). Also criticized was the availability and authority of the site representative of the university architect; this often led to a slow response or even no response when on-the-spot decisions were needed. Sometimes the university architect seemed to act as a kind of "passing mechanism" between the designer and the contractor, the faculty and the designer, and the faculty and contractor. The fact that neither the university architect nor the general contractor functioned as a problem solver only aggravated problems caused by the nature of the reconstruction project. The problems associated with the two phases done by competitive bid were generally similar, although there was perhaps somewhat less faculty interference (alternatively interpreted as "faculty checking") in phase IV than in phase III.

Time and Schedule Control

A logical and workable schedule submitted by the contractor and approved by the owner forms the foundation of the progress control system. However, in one competitive-bid phase no schedule was prepared and submitted for a long period after the beginning of work. Further, it was not updated in a timely fashion. As mentioned earlier, the contractor did not even seem aware of some of the work items covered in the contract, not to mention the "surprises" that might be encountered and affect the construction (it is possible that the contractor might have been conveniently unaware of certain requirements to obtain a better bargaining position on other issues). The project was poorly managed and occupancy was more than two months behind schedule; even then, the punch list was largely ignored (for more than a year in some cases) and some items were unfinished. Finally, a different contractor was eventually hired with the retained money to complete work on this phase of the project. In the other competitive-bid phase, the contractor determined soon after the project began that the completion of the work within the allocated time was impossible. Due in part to a low profit margin, the contractor used a conventional bar-chart schedule instead of computerized scheduling; although computerized scheduling was not required by specification, it was provided in phases II and III by the construction manager and general contractor, respectively. This phase was finished about six months behind schedule and has manifested many of the aforementioned difficulties.

Change Orders and Extras

Change orders and extras are common measures of efficiency in construction management; minimizing change orders and extras usually minimizes cost and time overruns. Change order and extra problems are aggravated when there is an adversarial relationship between the contractor and the owner (often due to a low contract price), because the contractor must do everything reasonably possible to either enhance his profit margin or reduce his loss. In one phase of this project the contractor simply transferred to the university architect all requests and claims by the subcontractors without carefully evaluating the appropriateness of these requests or claims in terms of the requirements stipulated in the contract. The extras required by the contractor in one competitive-bid phase were four times those in the construction-management phase. Problems occurred incessantly from the beginning to the end of the project. Although the initial cost (according to the bid) of this phase was lower than that of the construction-management phase, the final cost was almost the same (about 3% less), with the added problems of being more than two more months behind schedule and experiencing the difficulties described earlier. In retrospect, the university architect attributed the delay to the fact that the initial schedule was too aggressive and unachievable without perfect management by the general contractor. The other competitive-bid phase was even more seriously delayed by a wide variety of problems, and the reconstructed space was not opened for use at the start of the academic year. According to the contractor, about 200 requests for change orders were submitted. Numerous issues were raised throughout the reconstruction of this phase by the faculty involved in the process, but this space is now occupied (about six months late) without satisfactory solutions to many of these problems.

LESSONS LEARNED

Summarized here are the lessons learned by the trials and tribulations experienced during the first five phases (spanning about five years) of the multiphase reconstruction of the Technological Institute building on the Northwestern University campus in Evanston. Virtually all the indicated experience has been gained from phases II, III, and IV, because phase I involved an upgrading of the utility trunk lines with little disruption to ongoing activity in the building, and Phase V, which is still in the design stage, has provided little information to date. Each of phases II, III, and IV involved the reconstruction of a wing of the building (which has eight wings and a core) to accommodate the teaching, research, and administrative functions of a particular department (two departments in the case of Phase IV). The lessons learned are intended to be in-

J. Constr. Eng. Manage., 1996, 122(1): 44-54

terpretations of what the experiences of phases II, III, and IV have told us, interspersed with editorial commentary to place these lessons in perspective. The goal is to identify the problems encountered and the reasons for them, thereby suggesting where increased attention should be directed in a similar multiphase reconstruction project. There is no explicit attempt to conclude post facto what should have been done in a particular instance or to direct criticism at any individual or group because a specific course of action was not followed. Many of these lessons are strongly influenced by the fact that the design and construction activity took place in an academic and research environment instead of a more standard business setting.

Faculty Involvement

In the reconstruction of an industrial or commercial building, the decisions regarding the nature of the final product and the means to achieve it are usually made by a few top administrators, and the process of implementation offers the ultimate occupants little opportunity to exert much influence. In an academic setting, however, the faculty is usually accorded a much stronger voice in such matters, because each faculty member is usually a specialist in a rather narrow area of research that is little understood by others—especially administrators—and, therefore, can articulate the needs of a particular laboratory most clearly. However, administrators have the responsibility of running the university on a sound fiscal basis and must ultimately determine whether or not the indicated faculty needs for a given research laboratory lies within the project's fiscal constraints. Here, at the very outset of a university reconstruction project (especially for a highly technical building), lies the first problem; and the lesson is that a major effort must be directed toward reaching mutual agreement on the ground rules before serious design work is initiated. One strong suggestion is to accord the faculty a meaningful voice in the inevitable trade-offs needed to satisfy budget requirements, as opposed to having the university architect make such decisions on the basis of inherently different criteria.

Communication and Authority

Effective communication is always a challenge, and this is especially true when so many parties (administration, Reconstruction Committee, faculty, consultant, university architect, designer, construction manager, or general contractor, and subcontractors) are involved in the process. Although the seat of ultimate authority and the line of authority are generally well-recognized, strong emphasis must be placed on communication to explain the underlying reasons for a particular design or design change. There are always maneuvers to exert some degree of authority on a given issue, and this situation becomes increasingly complicated by the fact that the administration recognizes and endeavors to satisfy, insofar as possible, the needs of faculty to conduct cutting-edge research.

Flexibility in Design

In a research university the role of a given laboratory may change substantially in a short period of time (perhaps even during the period between formulating the program of requirements and actually constructing the laboratory). This suggests that a means should be in place to handle such unavoidable changes late in the reconstruction process, if they are indeed justified. Inherent in this flexibility requirement is that each laboratory must be sufficiently well-served with utilities to satisfy anticipated future needs.

Selection of Designer

The need to select a design firm with excellent experience in the design and reconstruction of buildings, which house a large number of technically sophisticated research laboratories, is especially important, and the personnel assigned to the project should have strong credentials in the design of facilities dominated by complicated mechanical and electrical infrastructure. Competent and efficient design will contribute toward offsetting a somewhat higher fee for the required expertise. A cooperative attitude and the willingness to interact with faculty are desirable attributes.

Selection of Contractor

As with the designer, the contractor should have experience with reconstruction projects involving extensive mechanical and electrical systems. An experienced and cooperative contractor can foresee potential problem areas and work with the owner, designer, and subcontractors to find creative solutions, which will result in saving both time and money. An adversarial relationship will undoubtedly offset any expected savings and result in a poorer final product. The five phases undertaken thus far have involved four different design firms (phases II and III were handled by the same firm), four different contractors (the phase V contractor will be the phase II construction manager), and two different contractual approaches. Consequently, the transfer of experience from one phase to the next has not been as efficient or effective as desirable. Strong consideration should be given to maintaining greater continuity in the professional teams involved in such a multiphase project.

Handling of Uncertainties

Since a reconstruction project always involves demolition and the inevitable uncovering of surprises, which are too indeterminate to anticipate in the design with any reasonable degree of accuracy, a basis must be established to handle these items. This challenge should be anticipated and met by requiring bidders to submit detailed price breakdowns for all work items; these unit rates could then provide the criterion for calculating the cost of a change order. In addition, contractors should be required to clarify any errors in the bid prices before any award is made.

Working Constraints

Contractors must be fully apprised of the constraints under which they will have to work. These include items such as the schedule of classes, levels of tolerable noise during designated time periods, access pathways that must remain open, needed protection against dust and odors, lay-down area, weight limitations on floors and elevators, height restrictions, and so forth. Adequate provision must be made for designers and contractors to become thoroughly familiar with the intricacies of the building.

Lump-Sum Contract

In general, a contractor estimates the cost of a project and then adds a certain amount to cover overhead, profit, and contingencies. In a competitive and difficult market, it is not unusual to reduce the expected profit to win a job. When this happens, the result is often a poor-quality job, an adversarial relationship with many claims for extras, or both. In at least one phase of this project the foregoing situation apparently occurred, and ultimately the university did not realize the financial benefit anticipated at the outset while having to tolerate an extremely difficult interaction with the contractor and a late

J. Constr. Eng. Manage., 1996, 122(1): 44-54

and incomplete delivery. The same result will probably occur for another phase of the project, but detailed data are not yet available. Although there is nothing inherently wrong with the time-tested value of this approach, the criteria for prequalification are especially important and some modifications in the contract seem appropriate to handle the uncertainties encountered.

Cost-Plus-Fee Contract with Guaranteed Maximum

Because of the high probability of surprises and/or changes in the original plan during construction, most contractors would probably prefer a cost-reimbursable fixed-fee type of contract. In this type of contract, the planned work is described in drawings and specifications, an approximate schedule is prepared for preliminary and general items of work, and an agreement is reached for: (1) Profit margins; (2) hourly rates for all components of the contractor's workforce, including construction-management personnel; (3) plant hires; and (4) materials. A modification of this type of contract is the maximum guaranteed price contract, in which the contractor agrees to complete the project at a cost that does not exceed some preestablished price. Both these contract approaches seem to hold special merit for a reconstruction project, with the added benefit that a general contractor who obtains a project through negotiation is more likely to function as a construction manager during construction.

Construction Management

The successful and timely completion of a project requires that some entity involved in the work assume the managerial role, and this was clearly demonstrated in the various phases of this project. A construction-management approach seems especially advantageous for a reconstruction project, and it worked well on the one phase where it was used. Any of several entities could serve as the construction manager; possibilities include the owner (university architect), designer, general contractor (by changing his traditional role), and a specialized construction-management firm. Alternatively, experience suggests that the general contractor resulting from a competitive bid did not function as effectively as a construction manager.

Preparation of Bid

Adequate time must be accorded the prospective contractors to examine the existing building, study the tender documents, and prepare the bid, especially in a lump-sum contract bid. The inadequate understanding of the terms of the contract by one contractor suggests that the time allocated for the bid preparation may not have been sufficient.

Construction Document

A computerized scheduling method, such as the critical path method (CPM), should be used to monitor construction progress and justify the responsibility and extent of any delays and the resulting cost. "Surprises (such as the oil waste discovered in the basement during one phase of this project) and/or changes in the work plan can alter both the contract amount and the completion date of the project. The basic questions in such cases are on how the cost of the extra work should be calculated and how much time extension should be granted; alternatively, if the contractor is still required to complete the project within the original deadline, what additional compensation is justified because of the imposed acceleration in the work plan. A network schedule, submitted by the contractor before the project starts and approved by the owner, can serve as a benchmark to define the responsibility for the delay (if any) and justify the overall time impact to the project. To obtain maximum benefit from this approach, detailed records of each circumstance should be maintained.

Role of University Architect

The Office of the University Architect has played a central role in this particular reconstruction project, as evidenced by the various organizational charts given, but effectiveness has been limited because: (1) Its exact function and responsibility were not well-defined or understood; (2) it was not responsive in a timely manner; and (3) it is not adequately staffed to perform the role it should probably play. In particular, the university architect could act as the construction manager and assume the responsibility for value engineering; coordinating during the design stages; evaluating and implementing faculty requests for reasonable changes; and controlling, inspecting, and supervising the construction work. Various limited aspects of this broad role have indeed been discharged, but the full role was clearly not assumed, nor was it ever intended. If the office were to function in the manner described, it would require additional personnel with the appropriate expertise. This expanded role of the university architect was suggested to the university administration on several occasions, but the decision was made to limit the role of the university architect and contract for the needed expertise with external companies in the local area. Although there is fundamentally nothing wrong with the use of such external expertise, there should be continuity over the life of the project; in the present situation the only continuity is provided through the Office of the University Architect, the possible use of the same subcontractors and suppliers, and the development of a master plan of the outset of the project (however, there have been several deviations from this master plan, and there will undoubtedly be more). The expanded role of the university architect in this case seems viable and consistent with the long-term operation of the university because there has been a high level of reconstruction or new construction for many years, and the prospect of this trend continuing seems probable. While the need for appropriate legal counsel, accountants, purchasing agents, and professional liability insurance will undoubtedly increase the cost of operating the office of the university architect to satisfy this expanded role, the savings realized by not having to retain external expertise (general contractors or construction managers) should more than offset these increased costs.

CONCLUSIONS

In the construction industry, as in most aspects of life, there are ways to address a problem. In particular, there are various approaches to handling a construction project, and each is well-suited for a specific set of conditions. By itself, no one approach can be judged "best," but, rather, any given approach must be evaluated in light of the prevailing job constraints. Within this perspective it seems unusual to use a conventional competitive-bid approach, which is generally considered most appropriate for a well-defined project with complete construction documents and a lesser number of uncertainties, to handle a multiphase reconstruction project with a high degree of uncertainties, stringent time constraints, significant operating restrictions, and much greater than normal communication problems. Indeed, the lessons learned on this project have clearly identified the difficulties encountered and the "false" economy realized by the use of such an approach. The situation has been increasingly aggravated by the frequent changes in designer and contractor for virtually every phase, thereby limiting the benefits in quality and cost that would ordinarily be gained from the accumulated experiences during the earlier phases. Although costs are always a major consid-

J. Constr. Eng. Manage., 1996, 122(1): 44-54

eration in every construction project, it must be recognized that "low bid" is inherently in conflict with achieving quality construction (especially for a building containing many sophisticated research laboratories) under restrictive working conditions (noise, dust, odors, interruptions, etc.), in a timely manner (to interface with the academic year calendar); when profit margins become unacceptably low, all performance measures deteriorate, an adversarial relationship ensues, and the anticipated advantages soon fade (albeit sometimes implicitly). The foregoing is especially true in the absence of effective project management with the authority to render timely decisions on the multitude of problems that arise during the course of the project; also, the contract documents should be sufficiently detailed to establish a strong basis for reconciling claims due to uncertainties or change orders. Accordingly, the early phases of this multiphase reconstruction project have demonstrated the importance of effective project management and the price paid for a lack thereof. Such management could be achieved by retaining a construction-management firm, having the general contractor serve as construction manager, empowering the design firm to act as manager, or increasing the capability of the office of the university architect to play the management role. The means to achieve effective project management may be accomplished in many ways, but the need to have it is irrefutable.

ACKNOWLEDGMENTS

The ideas presented in this paper were influenced by innumerable discussions with many individuals throughout the course of the project. A special note of thanks is extended to those who agreed to be interviewed for this study; their insight and experience contributed considerably to the lessons derived. Worthy of special mention are the many review sessions held with Charles H. Dowding, who, for a large part of the past few years, devoted more effort than he ever anticipated to one particular phase of this project. In addition, Charles H. Dowding and Gustavious P. Williams were extremely influential in developing the vision that was briefly explained in the early part of this paper.

J. Constr. Eng. Manage., 1996, 122(1): 44-54