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TECHNICAL PROPOSAL AND REPORT

STATE COMPUTER BASED BUILDING INFORMATION SYSTEM

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ABSTRACT

The Architecture Research Laboratory of the Department of Architecture proposes that the State of Michigan through the Bureau of Facilities develop and support a computer-based building information system for the purpose of providing information to support Life Cycle Cost-Benefit decisions by the several State Agencies and Institutions. The system is to include a dynamic master data base of cost and other performance information for designated cost centered buildings across the State. A building information center is to be established at the University of Michigan for the purpose of implementing the information system and carrying on related research.

Exploratory studies for this system have consisted of a review of the type of decisions required of the Bureau of Facilities and other State Agencies as well as the existing availability of data on buildings. A demonstration data base was assembled for 25 buildings from four different agencies and used to construct regression cost models for forecasting Life Cycle Costs for a current State office project in Lansing.

In addition to cost information, the demonstration included a study of energy consumption. A detailed computer thermal analysis using Weather Bureau data for simulation was conducted for the State Treasury building. Conclusions from these demonstrations support the hypothesis that the identification and analysis of cost-performance of existing buildings can, through the use of statistical methods, provide a basis for Life Cycle Cost-Benefit decisions from program budgeting through building operations.

1.0 FOREWORD

The need for consideration of the long term effect of the decisions made in obtaining and maintaining building space has, in the past few months, come into sharp focus in the energy crisis. However, this particular study was intiated and supported without the impetus of this or any other major crisis. The fact that the project was authorized, indicates that the Bureau of Facilities and other State Agencies are sensitive to the importance of considering long-term influences in making initial decisions in project planning and development. We, at the Architectural Research Laboratory, are appreciative of the confidence shown in the support of this effort by the State Department of Administration, John Dempsey, Head, and Almon Durkee, Director of the Bureau of Facilities with the consent of Senator Lane of the Joint Capital Outlay Committee.

We further appreciate the interest and support of James Wilson, Director of the Institute of Technology, University of Michigan, and James Lesch, Director of Research Development and Administration. This project has been supported jointly by I.S.T. and the Bureau of Facilities. The report of research to date and the technical proposal for continuing work along with the accompanying cost proposal are directed to the State of Michigan. An associated report on research potential will be made to the University. This initial four months study has been considered as exploratory research directed to 1) developing a longer range research plan - Phase A and 2) conducting a demonstration which would illustrate the use of the computer-based building information system - Phase B.

In approaching this study the staff of the project have worked closely with the Bureau of Facilities. In addition to Mr. Durkee, Ralph Seeley, William Hawes, William Roege and John Sullivan and their staffs have been most helpful. In fact, one should consider this a team effort. Mr. Sullivan served as direct liaison on the project. In addition to the Bureau of Facilities, Donald Wendell of the University of Michigan, Theodore Simon of Michigan State University and Ralph Lajeunesse of Ann Arbor Public Schools have been particularly helpful in providing

data for the demonstration study.

The goal of using Life Cycle Costing in Building Design has not been an issue, but the implementation of such has been of concern and this has been the subject of this study. We have assumed that Life Cycle Costing will require an appropriate information system as well as an understanding and confidence from the State Government, its Agencies, and the support professionals.

Concepts of Life Cycle Costing were considered by the writer since 1965 in conjunction with the comparative computer analysis of roof and wall systems. Computer programs developed in these studies were used in this project's demonstration study. Professor Crandall, an assistant on the project, has done work on forecasting costs based on historic data and is presently preparing a report on his recent study of building costs in Finland. Immediately prior to this project, the Laboratory's interest on Life Cycle Costing were centered on the dissertation study by John E. Williams. His study, entitled "A Model for Predicting Life-Cycle Building Costs: A Case Study of Two Public Universities in Michigan" is considered as basic background work for this proposal. Mr. Williams, an investigator on this project, extended the computer program he had developed in his dissertation to include alphanumeric and numeric data. This program with revisions has been used in the demonstration study and will be available for the projected (SCBIS) State Computer-Based Building Information System. In addition, we wish to thank Professor A. P. Oppermann, George Birrell, Edward Smith, Kaien Shimizu, Neal David, and David Stockton, who assisted in the project in the preparation of position papers, data collection, and in the demonstration study. We further wish to acknowledge the assistance and encouragement of Professors Metcalf and Paraskevopoulos of the Department of Architecture, without whose help the project would not have been possible.

Many University staff members have contributed to this research project. Especially do we thank James Greenway and Gretchen Haggerston of the Office of Research

Development and Administration, and Fanni Epstein and Becca Turner of the Architecture Research Laboratory.

By Willard A. Oberdick

Project Director

February 28, 1974

2.0 STATEMENT OF PROBLEM

"All Agencies considering projects involving State funds for either initial construction, the renewal of existing facilities, or in operating the facility, shall consider long-term costs toward minimization of such overall costs with maximum benefit to their respective program. Such consideration of Life Cycle-Costs Benefit can be considered in either planning or bidding or both".

The concept of Life Cycle-Costing implicit in the above hypothetical statement of what might be some future statutory requirement may be considered a long-term goal of this study and subsequent research developed therefrom. It would be impossible to reasonably implement such an approach at this time. The problems would be:

1) Where present methods of data collection on costs are reasonably complete, extrapolation therefrom is Agency oriented. Forecasting in these cases in general is not sensitive to building differences and as such is only used to prepare the Agency Budgets and special reports.

2) Presently, little if any information, is systematically collected on building performance and related to the planning process.

3) For effective programs, decisions on space planning and building development must remain close to the Agency concerned, however, for effective management and support by State Government responsible for broad allocation of public resources, there must exist a common understanding of goals, methods, and criteria. As there is some indication that this is even a concern with the present initial cost orientation, it will be of even greater concern with a policy of Life Cycle-Costing.

4) Any such change in approach must be supported by across the board appropriate expertise among professionals working directly or indirectly with the State or its Agencies. Such is presently minimal at best.

The program recommended in this report is intended to respond to these problem areas and permit the eventual implementation of Life Cycle Cost-Benefit space planning and building development as a public policy.

3.0 PROPOSAL FOR THE DEVELOPMENT OF A STATE COMPUTER-BASED INFORMATION SYSTEM (SCBIS)

3.1 Proposal - Goals and Objectives

It is proposed that:

1) The State of Michigan through the Bureau of Facilities, develop and support a computer-based building information system to serve the State Departments, State Universities and Community Colleges.

2) Major buildings within each of these agencies be designated as data cost-centers for purposes of identifying operating costs and performance characteristics.

3) Where necessary accounting be modified and electricity and fuel be metered for the designated buildings.

4) Research necessary to support life cycle costing be supported.

5) Building Information Center be identified at the University of Michigan with a limited scope of a) developing the aforementioned information system, b) conducting related research, and c) providing consultive support for the Bureau of Facilities.

Goals

1) Provide a system whereby staff of Agencies and Institutions can effectively consider life cycle cost and benefits in making the recommendations for both renovations and new projects.

2) Provide a basis for the formulation of policy of State support for renewal of buildings.

3) Provide a basis for the development of an integrated State program of technical support for the building industry and related professions.

Objectives

Assuming a period of three year development it is anticipated that the following objectives can be achieved:

1) At the end of year 1 the system and data base should be sufficiently

well developed for reliable forecasting of initial costs with a limited subsystem breakdown. This should include cost indices for the State.

The operating personnel from Bureau of Facilities, the State Departments and Institutions should be organized into an effective consulting group of system participants.

The Bureau of Facilities should have computerized certain of its operations and initiated use of the central information system for decision making. Further, the Bureau should have completed a trial collection of operational data from the Departments.

A test program of Life Cycle budgeting should have been initiated for continuation and evaluation during the remaining two years of the trial period.

2) At the end of year 2 the several participating Departments should be using the system for the comparative evaluation of their own buildings. The data collection system should be fully operational. Research on factors affecting the operation of the computer-based information system should have been completed and related to the test program.

Various simulation and computational programs should have been explored by the Bureau of Facilities. The Bureau should have operation programs supporting those aspects of its operation that are to be computerized.

3) At the end of year 3 the test program of Life Cycle budgeting should sufficiently be developed for the assessment of the benefit of SCBIS for life cycle costing. Recommendations should be available for the continuation of the system within the scope of the participating State Agencies and Institutions or its possible extensions to other public supported institutions. Continuing education programs should have been conducted in the Agencies as well as in the professions.

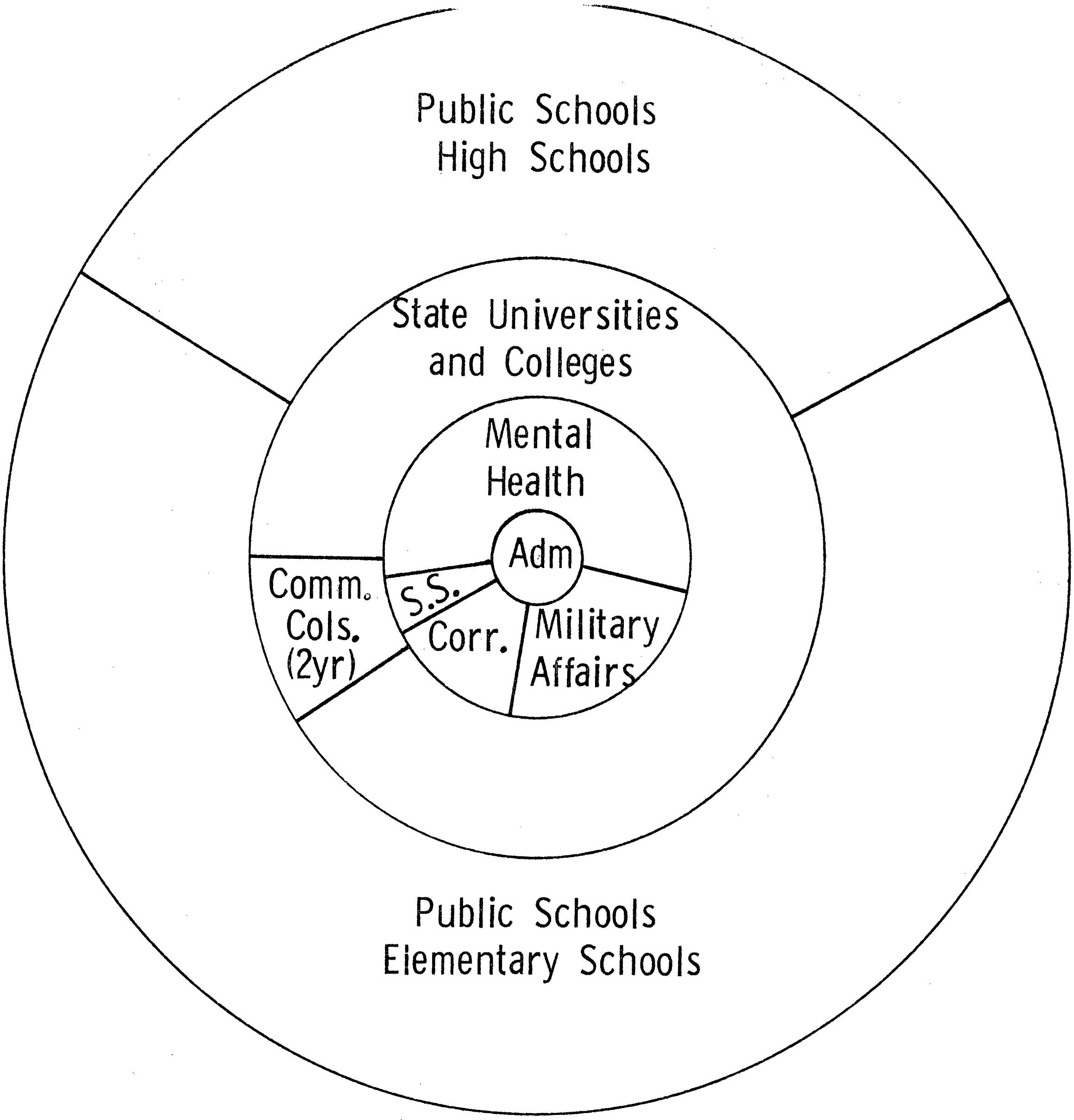
2 CHARACTERISTICS AND OPERATION OF SCBIS

2.1 General

As noted, the proposal includes participation by State Departments, state universities and community colleges. The building inventory shown in Figure 1 indicates the potential of including the university and community colleges in addition to the state government buildings. First, it is necessary that a large inventory of buildings be included in the data set and second, the potential for benefit to the State is increased. Further, the large universities have in general a data systemm base equivalent to that of the Bureau of Facilities. An examination of decision responsibilities of several universities indicates that most decisions affecting new building projects and particularly management of the physical plant are made by the university concerned. This quasi-independent status presents a challenge for the proposed system, i.e., the system must be flexible to permit each Agency to use their own portion of the data base for information retrieval and the entire data base for forecasting. The independent status of the community college is also unique. Each unit could furnish summary reports at selected intervals to the Legislature through the Bureau of Facilities.

2.2 Role of Bureau of Facilities

The Bureau of Facilities has the responsibility for programming, developing and operating the State Government Centers. They also presently have a primary responsibility for administering capital funds in respect to the State Departments and Universities with a somewhat lesser role in relation to the larger Universities. It is our conclusion that the Bureau with its professional staff is the logical group to assume leadership in the development and use of the system, particularly as it expands its computer resources. We would anticipate the Bureau would assume the system user role for its own area of management as well as that for the State Departments and smaller universities requesting such service. For the others it would provide an advisory service.



Building Areas - Total Square Feet

Administration	3,000,000
Corrections	3,300,000
Mental Health	12,300,000
Military Affairs	5,300,000
Social Services	1,300,000
Public Schools	180,000,000
Four Year Universities and Colleges	58,900,000
Two Year Community Colleges	6,450,000

FACILITIES DEVELOPMENT -
STATE FUNDING
Space Inventory - Operating
Interrelationships
December 1971

Figure 1

During the development stage it would seem advisable that the research and development be a joint effort, i.e., both Bureaus' staffs involved in the information project and the Building Information Center staff be involved in major decisions and in periodic evaluations of progress.

It is suggested that the Bureau organize an exploratory seminar meeting with the Department and Institutional representatives at the start of the project and continue such a coordinating role throughout the study.

2.3 Building Information Center

It is recommended that a Building Information Center be established within the administrative structure of the Institute of Science and Technology at the University of Michigan. The Architectural Research Laboratory would be responsible for the development of SCBIS and related research with funding through the Bureau of Facilities. The intent of this arrangement is that of maintaining a functional tie with the State Government as well as a logical independence in relation to the separate institutions. Further, any such center should be dynamic in character, responding to changing need of users as well as promoting change resulting from research. The logical interdependence of application, research and education would seem to support this view.

Two types of computer usage are anticipated. First, the historic data base will require a relatively small amount of input-output and moderate storage and C.P.U. capacity along with an interactive system with remote terminals. It is recommended that the U of M-IBM 360/67 be used for the 3 year development phase of SCBIS. Second, it is anticipated that other aspects of the development work will involve larger input and output appropriate to the batch mode. This would logically be developed in conjunction with the Bureau of Management Science using the State's computer system. The latter would involve computer application directly related to the Bureau's project management and building management operations.

In addition to the development of SCBIS, the center would be responsible for the research identified in this proposal as well as supporting the educational and user applications of the system.

2.4 Information - Data Collection

To this point in the proposal it has been suggested 1) that SCBIS include State Government, State Departments, state universities and community colleges, 2) that data-centered buildings be designated in each agency with accounting and metering being building centered, and 3) that initial cost and capital improvement as well as appropriate descriptors and performance data be recorded for all buildings included in the data base. It should be noted that the specific agencies to be included in the system will undoubtedly depend on policy decisions of the agency as well as of the Legislature or its agents. The suggestions in these recommendations for their inclusion does not imply prior contact or approval.

The selection of data-centered buildings within each agency should be based on the following: 1) that operating costs and performance data within an agency's operation can reasonably be identified for the building; and that 2) the size of the specific facility is sufficiently large to be significant. Buildings less than 20,000 sq. ft. might be excluded except as they may be in a group of identically functioning buildings; or buildings may be excluded where their use may be so varied or unique as to be of limited value in the data base.

A primary concern in this study has been the decision level on detail that is to be supported by the information system. As this proposal recommends the use of regression analysis of historic data to develop models for forecasting, certain limitations are involved. First, a lower order of decision can not be supported than that for which data has been collected, i. e., one cannot forecast the cost of a particular building system if no costs have been identified for such. However, it is possible to forecast the cost of the particular architectural work with a particular system if a sufficient number of buildings of that structural type are included in a set. Second, that for the latter to be possible, identifiable descriptors or codes must be included.

It is recommended that data be collected on the basis of normal contractual divisions, i.e., Architectural, H.V.A.C., Plumbing, Electrical, Site, Equipment, and Professional Fees, as noted in Figure 2.

The parameters to be identified for each category of cost centering should have a logical dependence on the factors to be considered. Descriptors and performance factors should cover the range of characteristics for the buildings considered. The parameters identified in the demonstration studies could form a reasonable starting point for SCBIS, however, these should be checked before starting the collection as noted in the comments under research.

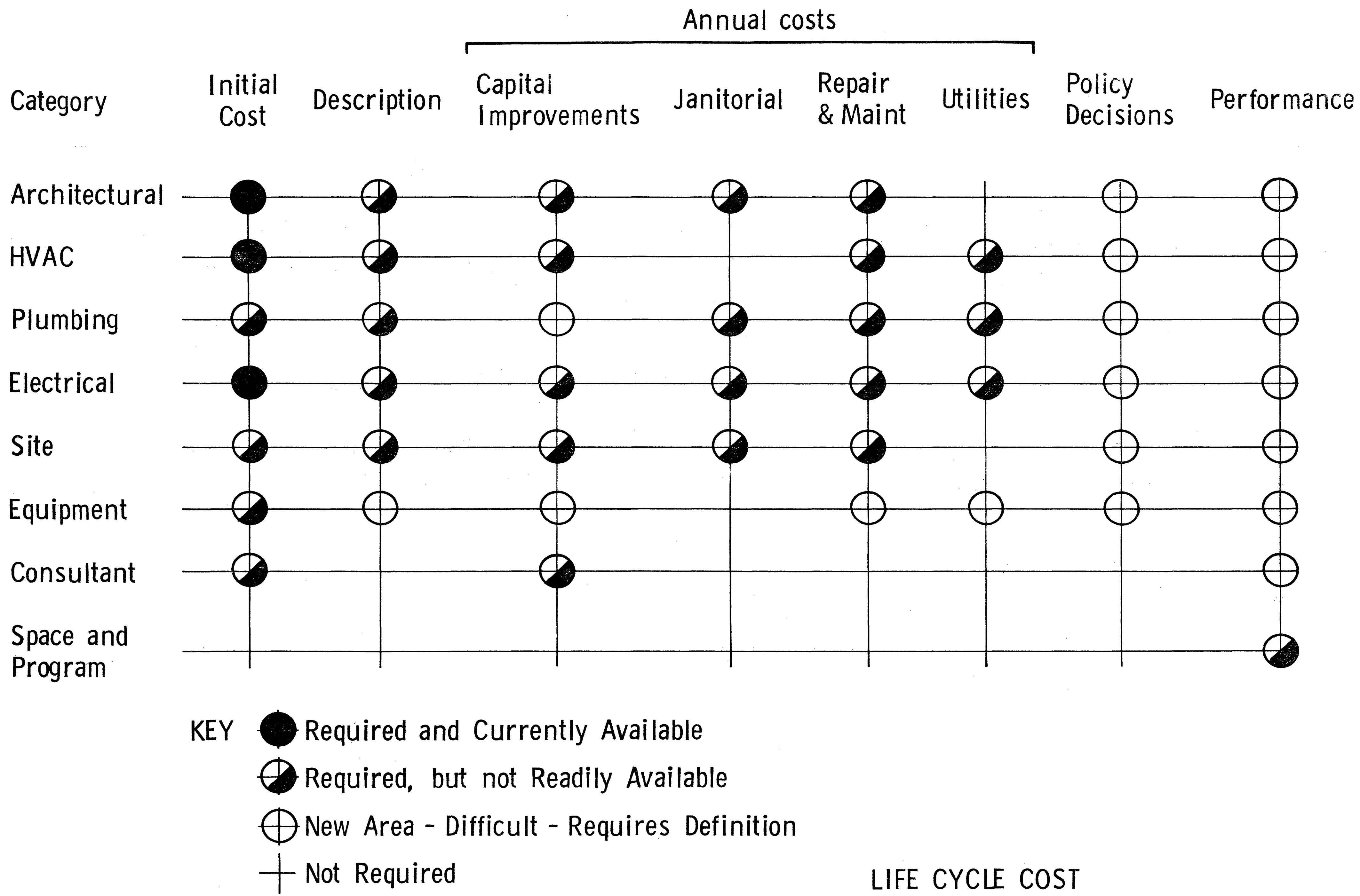
A system of specification of measures, procedures and checking will need to be identified by the Building Information Center.

Much of the focus of the projected effort relates to assembling an effective data base. This data base should be considered to be a dynamic one, with buildings being added and removed, operating data for the current year added and a previous year dropped. This data base, operating computer software, data collection and data usage become part of the information system.

3.3 Research

Within a broader definition this entire proposal may be considered a research effort. However, as the Demonstration Study has provided additional evidence of the feasibility of using regression analysis for developing satisfactory cost models, the basic premise of SCBIS is not assumed to be in question. However, within the total concept certain questions need further study in depth. It is proposed that the following subjects be identified as research to be accomplished within the Building Information Center during the three year period.

1) Identification of the most logical parameters for which data is to be



LIFE CYCLE COST
Data Availability
Figure 2

collected. Project experience, agency agents' experience, and that of other professionals should be systematically explored.

2) Exploration of the factors influencing varying initial and operating costs across the State with the objective of identifying indices for relating costs in reference to time and location.

3) Explore approaches to the consideration of stochastic variables such as capital improvements within the context of SCBIS.

4) The concept of measuring benefit levels of performance should be explored and an acceptable approach incorporated into SCBIS. Refer to the John Williams' position paper on this subject in the appendix.

5) Explore the feasibility of the use of gaming simulation as an educational tool to promote the use of life cycle costing. Recommendation for funding of such an effort would logically result from this study.

6) Explore the role of State in encouraging research in support of a performance approach to building codes. This is in anticipation of future needs and not directly related to L.C.C.

It is anticipated that the research embodied in this proposal will stimulate other related research particularly in the Doctoral Program of the Department of Architecture. To encourage this, it is proposed that a research grant be made available each year for a doctoral student submitting the best proposal as determined by the Bureau of Facilities and the Center.

.4 Support of Continuing Education

One of the real values of SCBIS will be the catalytic effect on the continued education of professionals in Life Cycle Costing. Specifically, it is recommended that the Building Information Center develop a short course appropriate for use with staffs of the Bureau of Facilities and other agencies as well as with the Department of Architecture, University of Michigan. This use would be followed with instructions for the selected staffs of the agencies and institutions. During the 3rd year the

Department of Architecture or the Professional Societies would be encouraged to conduct continued education courses. The timing is important in the latter case, as the concept of Life Cycle Costing should not be promulgated until the State is ready to support the concept. Videotape and computer support will be explored as they may be appropriate.

It is anticipated that the data bases will be useful research instruments for future studies beyond that noted in the previous section. It is hoped that the State will have versions of the data made available to the educational institutions for student use.

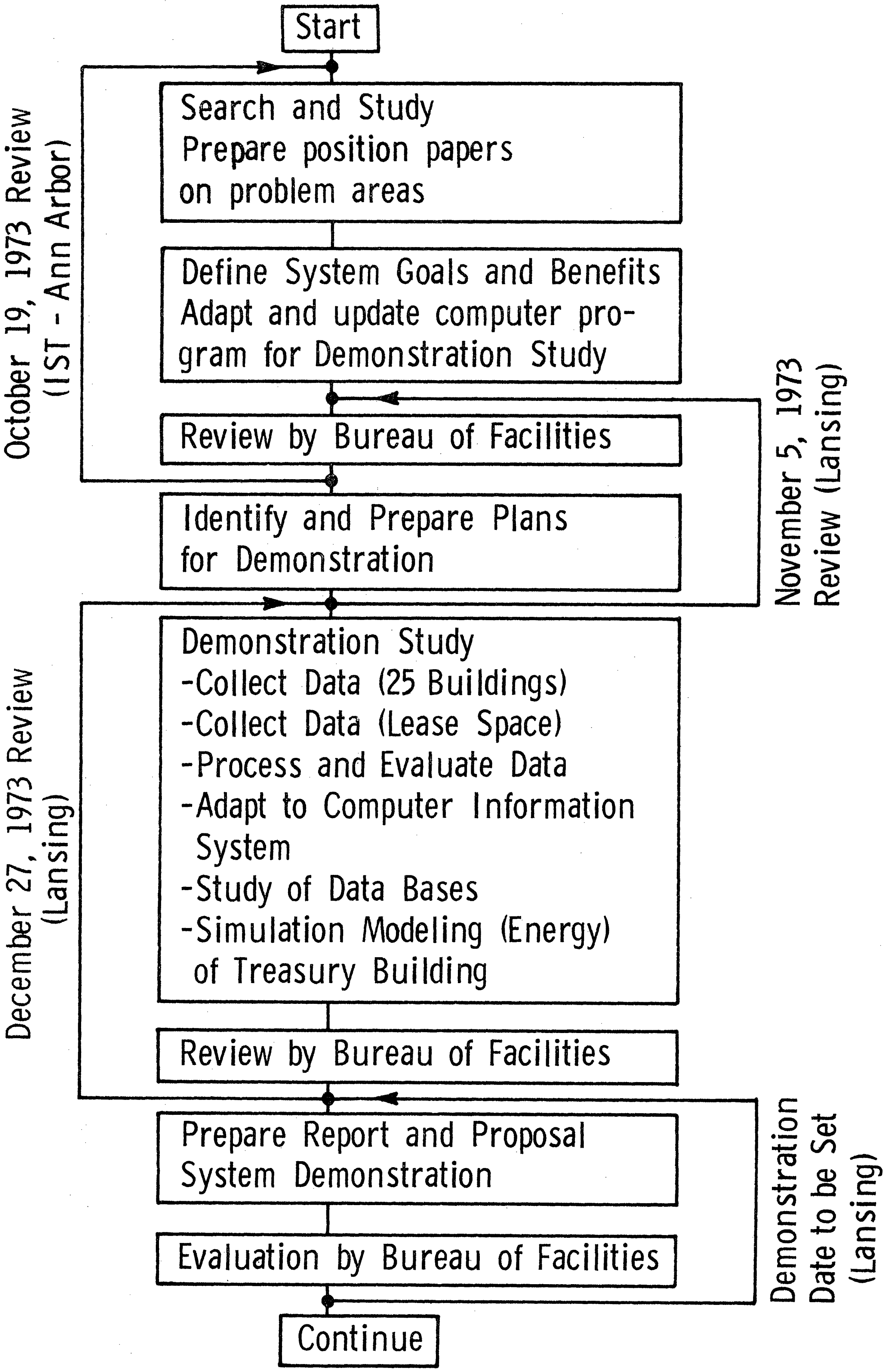
.0 BACKGROUND OF RECOMMENDATIONS - REPORT OF PHASE A

.1 Research Approach

The proposal incorporated in the previous section has resulted from the research study funded by the State Department of Management and Budget (formerly Department of Administration) and the Institute of Science and Technology of the University of Michigan. The proposal in effect incorporates the conclusions from this study. This and the following sections are intended as a report of the research and as such provide background information for the recommendations.

In this exploratory study, effort was focused on investigating four areas which were considered fundamental to the implementation of Life Cycle Costing. LCC is assumed to involve the systematic consideration of long term effects in program formulation, budgeting, development and operation of building facilities, the space component of total program consideration. The procedures and relationships of activities followed in this research study are noted in Figure 3.

First area of concern was that of involvement of the "decision makers" in the process not only of formulating an approach to LCC, but also in implementing the system. As noted in Figure 3, the management team of the Bureau of Facilities were involved with periodic reviews. These were attempts not only to review progress of the research, but also to determine specific information on decision concerns both



BUILDING INFORMATION SYSTEM
RESEARCH
PHASE A & B

Figure 3

at the Bureau of Facilities and at other agencies which receive planning and capital funds from the State of Michigan. It was hoped that with their involvement in this study the proposals for LCC would be relevant and consequently, if adopted, would result in an effective State program. The results of the study of decision responsibilities are included in the next section.

The second concern was that of exploring the utilization of the computer and analytical tools heretofore not commonly applied in this problem area.

Investigation of computer applications were focused on the demonstration study. The computer program "Life Cycle Cost System", originally developed by John Williams as part of his dissertation, was available to this project. Mr. Williams expanded this program to include storage and retrieval of alphameric information. Other changes included: 1) the use of user codes to accommodate the requirements of a diverse users' group, and 2) implementation of commands permitting users to utilize agency oriented data bases within a context of a master data base. The revised program used in the demonstration study is identified as "Information System Program".

Other computer programs were developed to support the use and operation of a projected master data base.

The computer programs on thermal analysis developed by the writer were used in the demonstration study without revision. Extension of the programs were explored with the intent of providing a 24 hour modeling of selected buildings. However, these were not implemented because of a lack of time and resources budgeted for this study.

Although not one of the original objectives, this project has had a catalytic effect of stimulating the "computerization" of certain of the Bureau's activities. Remote terminal access has been arranged with the University of Michigan IBM 360/67 for a trial period. To support this challenge, a continuing consultive role by the Architectural Research Laboratory is assumed for the proposed Building Information Center.

Concepts of applications of Probability and Statistics, Mathematical Programming and Simulation were explored by project staff. Brief descriptive statements on these techniques are appended to this report. Regression analysis of historical data on costs and other descriptors is proposed as a primary technique for examining the data, formulating relationships and developing mathematical models for forecasting LCC. This approach is used in the demonstration study.

Another approach was used in modeling the thermal (energy) performance of the State Treasury Building. In the latter case, Weather Bureau data was incorporated in the model to simulate the building performance.

Recent research in the use of simulation models with particular emphasis on the uses of queueing theory suggest practical application in building programming. A brief discussion of simulation models is included in the appendix. A more detailed discussion is included in a 30 minute videotape by Kaien Shimizu, prepared as part of this project study.

An effective means of considering uncertainty is fundamental in long-term forecasting of LCC. The problem here is easily illustrated by the recent events related to the energy crisis. The 1973 changes in policy and pricing structure for energy would hardly have been anticipated in 1967. However, the long-term influences will not be as major as those suggested by the day to day fluctuations; as an example, the policy decisions of energy conservation may well counter the effects of price escalation. Probability theory will need to be used to consider the effects of stochastic variables, those involving uncertainty, particularly as it may be used to identify the importance of a particular factor in the decision.

The original proposal stated that the development of analytical tools such as mathematical programming, simulation models, and computer technology, has made possible a more exacting systematic consideration of factors which heretofore have been considered by intuition. This study supports this position and has demonstrated certain aspects, but the major exploration of the application of these tools remains a challenge.

The third major concern in this preliminary study wasy that of assessing the availability of a sufficiently large historic data base to support the type of decisions required in LCC. The original premise of this proposal was that the State of Michigan provided this resource. Further study supported this point assuming that the universities and colleges are included in the initial data base.

Investigation of data availability was focused on the demonstration study in assembling data from several different agencies. No attempt was made in this exploratory study to conduct a comprehensive survey of all state agencies. General information on the several public universities, State agencies and departments was obtained from a 1972 state-wide survey conducted by the Governor's Special Commission on Architecture.

Specific data on the buildings used in the demonstration study were obtained through interviews, staff search of the agency's documents and by agency staff search in response to specific requests.

The fourth concern of this study was the operational relationships between the Bureau of Facilities and major institutions of Higher Education. Two approaches were used. First, the Bureau's Management Team provided the staff with an overall view and second, the demonstration study was used to explore the feasibility of specifically including the University of Michigan and Michigan State University in the LCC information system. Limited demonstration of the use of Building Information System were conducted at both schools. The selection of these two Universities and the Ann Arbor Public Schools was one of expediency and their selection for this study does not imply any particular preference except as to the size of the physical plant. Implementation of SCBIS will certainly require consideration of all of the public universities and colleges.

.2 DECISION RESPONSIBILITY

One of the major questions addressed in this study was the level or type of decision to be supported by the proposed building information system. Figure 4-6

ACTIVITY-AGENCY RELATIONSHIPS
DEVELOPMENT AND OPERATION OF
BUILDINGS. STATE FUNDS

USER / ACTIVITY — Agency	State Government	State Agencies	University-Colleges (Planning Act)	University - Colleges (Non-Planning Act)	Community & Junior Colleges	Secondary Schools Local School Boards
PROGRAM						
Budget Request		D/R	D/R	S/E	S/E	S/E
Program Development		S/E	S/E	S/E	S/E	S/E
Select Architect		D/R	D/R	S/E	S/E	S/E
Select Site				S/E	S/E	S/E
STUDY						
Program Analysis		S/E	S/E	S/E	S/E	S/E
Preliminary Design		A/R	A/R	R/A	R/A	R/A
DOCUMENTATION						
Select Prof. Contractor		D/R	D/R	S/E	S/E	S/E
Prepare Construct. Documents		A/R	R/A	R/A	R/A	R/A
Compliance Review		A	A	S/E	A	A
Bidding		A/R	R/A	R/A	R/A	R/A
CONSTRUCTION						
Select Contractor		A	S/E	S/E	S/E	S/E
Supervision		A	S/E	S/E	S/E	S/E
Acceptance		A	S/E			
OCCUPANCY						
Budget Request		D/R	D/R	D/R	S/E	S/E
Management		S/E	S/E	S/E	S/E	S/E
Repair and Maintenance		S/E	S/E	S/E	S/E	S/E
Evaluation		---	---	---	---	---

Key:

D/R	Draft & Recommend	A/R	Approve & Recommend
R/A	Review & Approve	S/E	Study & Execute
A	Advise only		

FIGURE 4

ACTIVITY-AGENCY RELATIONSHIPS
DEVELOPMENT AND OPERATION OF
BUILDINGS. STATE FUNDS

Bureau of the Budget

ACTIVITY / Agency	State Government	State Agencies	University-Colleges (Planning Act)	University - Colleges (Non-Planning Act)	Community & Junior Colleges	Secondary Schools Local School Boards
PROGRAM						
Budget Request	A/R	A/R	A/R	A/R	A/R	
Program Development	A/R	A/R	A/R	A/R	A/R	
Select Architect						
Select Site						
STUDY						
Program Analysis						
Preliminary Design						
DOCUMENTATION						
Select Prof. Contractor						
Prepare Construct. Documents						
Compliance Review						
Bidding						
CONSTRUCTION						
Select Contractor						
Supervision						
Acceptance						
OCCUPANCY						
Budget Request	A/R	A/R	A/R	A/R		F
Management						
Repair and Maintenance						
Evaluation						

Key:

D/R	Draft & Recommend	A/R	Approve & Recommend
R/A	Review & Approve	S/E	Study & Execute
A	Advise only	F	Formula only

FIGURE 5

ACTIVITY-AGENCY RELATIONSHIPS
DEVELOPMENT AND OPERATION OF
BUILDINGS. STATE FUNDS

Bureau of Facilities

ACTIVITY / Agency	State Government	State Agencies	University-Colleges (Planning Act)	University - Colleges (Non-Planning Act)	Community & Junior Colleges	Secondary Schools Local School Board
PROGRAM						
Budget Request	D/R					
Program Development	S/E	R/A				
Select Architect	S/E	R/A	R/A			
Select Site	S/E	S/E				
STUDY						
Program Analysis	S/E	A				
Preliminary Design	A/R	A/R	A/R		A/R	A/R
DOCUMENTATION						
Select Prof. Contractor	S/E	R/A	R/A			
Prepare Construct. Documents	R/A	R/A				
Compliance Review	R/A	R/A	R/A	R/A	R/A	R/A
Bidding	D/R	R/A	R/A	R/A	A/R	A/R
CONSTRUCTION						
Select Contractor	S/E	S/E	R/A			
Supervision	S/E	R/A				
Acceptance	S/E	R/A				
OCCUPANCY						
Budget Request	D/R	A				
Management	S/E					
Repair and Maintenance	S/E					
Evaluation	I					

Key:

D/R	Draft & Resommend	A/R	Approve & Recommend
R/A	Review & Approve	S/E	Study & Execute
A	Advise only	I	Informal - not systematic

FIGURE 6

summarizes what might be identified as the existing agency interrelationship as related to decision responsibility. The activities noted relate only to the space (building) component of a total agencies' program. The final authority for the total State Building program, of course, rests with the State Government except as it may be particularly shared with those Universities opting for this responsibility.

Activities related to the formulation of a building budget request through the acceptance of final project, for those projects funded through the Planning Act, are principally centered in the Bureau of Facilities with immediate authority in the Joint Capital Outlay Committee of the State Legislature. This relationship would also apply to major renovations, i.e., over $10,000. Management of buildings are however, more directly related to the agencies except for the State Government buildings in the central and secondary government complex. Although this split responsibility might appear to be a problem in implementing LCC, the Bureau of Budget does have responsibility for approving budget requests for both capital and operating expenditures. Further, since both the Bureau of Budget and Facilities are in the Department of Management and Budget, the organizational relationships can logically support LCC. It is suggested, however, that the Bureau of Facilities organize a User's Group from the several State programs including Universities to aid in the development of LCC. The members of the group would have parallel roles to that of three division chiefs in the Bureau of Facilities, i.e., Design, Construction and Facilities Management.

Another point to note is that the present state policy is that of managing the program-build process from the owner's viewpoint rather than assume selective roles as professionals. Principal decisions relate: 1) to the budget-benefit analysis for new projects as well as that of the operation of existing facilities and 2) evaluating bid proposals and contract performances. The level of detail to be supported in the latter situation depends on the strategy followed in managing the contracts. The more recent use of "Fast Track" with a professional constructional manager implies concern for detail commensurate with contract breakdown. In terms of initial costs, the "Review and Approve" would mean evaluating the completeness bids and the expected performance. This can be an evaluation of professional recommendations as well as their reasonableness in respect to program and budgetory requirements.

It is anticipated that the first stage of implementing LCC will involve decisions by the Bureau of Facilities on Life Cycle Costs and Benefits with bids taken only on initial costs. This situation will require a more detailed level of decision responsibility than that required for the full implementation of Life Cycle bidding. This is precisely the point why it is logical for the State to support the development of LCC, providing the leadership for advancing the entire concept.

4.3 DATA AVAILABILITY

Agencies collect only that information they can use directly or are required to supply to State or Federal Government. Accounting may not be building cost-centered if there has been no need for such a breakdown. If a particular project is self liquidating, care will be taken to meter and cost-center the building to ascertain its true life cycle costs. College instructional space inventory and usage are meticulously monitored to provide appropriate reports to the State and the U.S. Department of Health, Education and Welfare.

Required data categories and general current availability among the State agencies is summarized in Figure 2. The following short statements on specific situations are not necessarily typical but do indicate the nature of the problem. The Bureau of Facilities does not building-center repair and maintenance costs. The Department of Public Health does not cost-center any buildings. Michigan State University does not meter steam in any of major buildings. Ann Arbor Public Schools has only two years of records because of a recent fire. Assuming the requirements of a LCC historic data base, these may be considered deficiencies. However, except for these types of problems we have observed a most carefully kept record system among three of the major building "owners" namely: Bureau of Facilities, Michigan State Universit- and the University of Michigan. We would anticipate the same to be true for the other major Universities.

These comments on data availability apply to cost data. Information on policy decisions and performance is essentially a new area. To some extent operating costs may be considered a measure of performance or the accommodation of the number of building users as per design intent a measure of adequacy. The performance measures noted in Figure 7 represent a more detailed approach. Such an approach, although not complete would be useful in supporting the first stage of LCC. A logical structure for identifying benefit is included as an appended statement.

During the course of this study locational cost differentials were explored. To this end it is recommended that buildings in many different areas be included in the initial historic data base to provide a basis for developing locational cost indices. A summary statement on this problem is also appended to this report.

The categories noted in Figure 2 follow the normal contractual divisions, and would appear to be a logical starting point for a LCC data base. Consistency of life cycle information is a problem even at this breakdown. As an example one might note that metered electric energy normally covers lighting, building and mechanical equipment. Accordingly the total energy costs for a particular type of mechanical equipment can not be measured, although repair and maintenance can be so identified as that cost centering is reasonable. To account for these distinctions it will be necessary to develop simulation models similar to that used in the demonstration study. It is anticipated that consistency of information will be a problem during the early period of development. Emphasis will be placed on those factors which prove to be more significant.

Some difficulty was experienced in collecting descriptive information on the buildings used in the demonstration study. The problems should be minimized with a firm set of guidelines. Direct building observations may be needed in addition

CATEGORY:	UNIT	FACTOR	MEASURES
ARCHITECTURAL	Flooring	Maintenance--Appearance	(GSA Rating--Level of Service--Work Standards)
	Interior Partition	Flexibility Privacy	Changes/Year DBA Rating
	Exterior Walls	Appearance Acoustic Thermal	Experts Rating DBA Rating Unit Transmission
HVAC	Refrigeration Component	Efficiency Down Time	Energy Consumed Hours/Year
	Mechanical System	Comfort Zoning Down Time	Control Capability-Rating Sq.Ft./Zone Hours/Year
ELECTRICAL	Electrical System --Lighting	Flexibility Quality	Switching Sq.Ft./Switch V.C.Rating
GENERAL	Building	Suitability Siting Occupant Assignable Space	Expert Rating Expert Rating Unit/Occupant Percent Assignable
	Site	Maintenance--Appearance	Work Standards Lighting Quality

PERFORMANCE MEASURES

FIGURE 7

to use of previously recorded information. Information on new building projects would logically be supplied by the designing architects and engineers.

4.4 DISCUSSION OF ALTERNATIVES

During the course of this study several alternative strategies were considered. These are summarized in Figure 8. Although each strategy represents certain specific characteristics, however, the alternatives should not be considered mutually exclusive. Strategy 1 is the recommendation included in section 3 of this report. Strategy 3 involves the use of separate historic data bases with independent action by the several agencies. Strategy 2 involves the employment of Cost System Engineers, Inc., Fort Worth, Texas, to provide consulting services on request. This firm presently is a consultant for the Michigan State Housing Authority. Strategy 1A is a combination of Strategy 1 and 2, in effect retaining the cost consultants for support of initial cost estimates for the Bureau during the first year and back up support during the second and third year, when LCC will be tested.

5.0 DEMONSTRATION STUDIES - PHASE B

5.1 APPROACH AND OBJECTIVES

The objectives of this phase of the research study was

1) to structure and conduct a demonstration which would illustrate the use of the projected computer based building information system

2) to obtain information and/or develop a data base which would be of practical use by the Bureau of Facilities

3) to explore the availability of data and the implications of using a heterogeneous data base.

The ultimate goal of the computer based information system is that of supporting decisions related to programming - development and operation of building decisions. The most logical demonstration would then be that better decisions can be made using LCC than with initial cost orientations. However, in formulating this particular

LIFE CYCLE COST-BENEFIT INFORMATION SYSTEM

	STRATEGY 1	STRATEGY 1A	STRATEGY 2	STRATEGY 3
Description				
General	-SCBIS: Building Information Center at U-M; Master Data Base for all State Agencies	-SCBIS: Building Information Center at U-M with outside cost consultants; Smaller data base than in (1)	-Cost Consultants provide service on request; Cost Systems Engineers, Inc.	-Adaptation of as is Demonstration System; Independent Agency Approach
Users	-Bureau of Facilities, State Departments, Universities and Colleges	-Bureau of Facilities, Major Universities	-Bureau of Facilities	-Bureau of Facilities, and/or State Departments
Data Base	-Initial costs, operational costs, performance, information for 150 buildings	-Initial cost-operational costs, performance information for 60 buildings	-Provided by consultants	-Initial costs, operational costs, Bureau of Facilities, 20 buildings U-M, 30 buildings
Development				
Responsibility-Administration	-Bureau of Facilities and U-M	-Bureau of Facilities and U-M	-Consultants	-Bureau of Facilities or U-M or MSU
Data Collection	-Building Information Center and Agency	-Building Information Center and Agency	-Job by job requests	-Separate Agency
Funds-Source	-Bureau of Facilities	-Bureau of Facilities	-Bureau of Facilities	-Separate Agency
Time Period	-3 years	-Immediate and 3 years	-Immediate	-6 months
Output	-Information retrieval	-Information retrieval	-Reliable Cost Estimates for study through design development	-Information retrieval for comparative purposes
	-Modeling for forecasting life cycle cost-benefit study	-Modeling for life cycle cost-benefit forecasting for study and budgeting	-Value engineering	-Models for forecasting for program budgeting; Difficult for Bureau of Facilities
	-Design development	-Simulation applications		
	-Comparative reports from several Agencies			
	-Simulation applications			
Benefit				
Bureau of Facilities	-Support of management role - LCC decision making	-Support of LCC - benefit analysis and direct answers	-Direct answers	-Improved monitoring of existing facilities
Other Agencies	-State Agencies operating with common methods toward common goals	-Limited to Agency involved	-None	-Limited to Agencies involved
Education	-Bureau of Facilities - Leadership in Continuing Education	-Intra-agency education	-None anticipated	-None anticipated

LCC - ALTERNATIVE STRATEGIES

FIGURE 8

research study, it was realized that this would be more of a long term goal than an immediate objective. Consequently, the objectives were limited as noted above.

As a matter of expediency it was hoped that

1) "on the shelf" computer software could be used

2) the University of Michigan computer could be used as the available software had been developed on this system.

The U of M-M.T.S. was made available through the cooperation of the States, Division of Management Science and the U of M Computer Center. The States terminal (NCR 260) with a trunk telephone line was used with the M.T.S. for demonstration in Lansing.

Computer software, however, did require considerable debugging as changes were made in the Information System Program to better illustrate an operation of a data center with a master data base. No changes were made in the basic software used for the thermal simulation except that adapting the data to a fiscal year basis necessitated changes in auxiliary programs.

Emphasis in Phase B was placed in three areas, namely:

1) assembling a data base of historic data on State owned buildings and on State leased buildings in the Lansing Area;

2) demonstrating the use of the Information System Program with these data bases;

3) analyzing of a State office building using Thermal Analysis programs

2 DATA BASE - COST & DESCRIPTIVE DATA

The historic data base consisted of 25 office and classroom buildings, 9 selected from the University of Michigan in Ann Arbor, 5 from Michigan State University, 6 from State government complex in Lansing, and 5 schools from the Public School System in Ann Arbor.

The objective of this particular selection was to explore:

1) accessibility of data from the several agencies

2) problems of consistency

3) explore the type of parameters needed for a more diverse group of buildings.

Each of these points are made to contrast this effort with that of John Williams in his detailed study of U of M data for his dissertation, the results of which were available prior to the start of this demonstration. Further, the Bureau wished to have information on the office complex in Lansing and as such were included.

The following parameters were identified for this trial data base. In each case the variable name and description are included.

A) General Information (Numberic and alphameric; refer to file REFERCODE in the appended report)

LOCATION	-City
BLDG.TYP	-Principal use + code
ARCHITEC	-Name
ENGINEER	-Name
GENL.CON	-General Contractor
MECH.CON	-Mechanical Contractor
ELEC.CON	-Electrical Contractor
FOUN.TYP	-Foundation-Footings description
AGENCY	-Agency responsible for operation
STRU.TYP	-Description of Structure
EXWA.TYP	-Description of Exterior Wall
GLAS.TYP	-Description of Glass
LIGH.TYP	-Description of Lighting System
AIRH.TYP	-Description of Air Handling System
REFR.TYP	-Description of Cooling
HEAT.SOU	-Primary Source of Heating
POWE.SOU	-Source of Electricity
PART.TYP	-Description of Interior Partitions
ROOF.TYP	-Description of Roof Type
FLO.TYP	-Description of Flooring

B) Building Descriptors (Numeric Only)

FLO.AREA	-Floor area-sq. ft.
VOLUME	-Cu. ft.
ASSIG.AR	-Assigned area-sq. ft.
SITERAREA	-Sq. ft. total including buildings
PARKING	-Number of cars
ROOFAREA	-Sq. ft.
WALLAREA	-Sq. ft. of exterior wall
GLAS.ARE	-Sq. ft. of exterior glass
FLOOR.NUM	-Number of floors-including basement

LIGH.ZON	-Number of room switches
MECH.ZON	-Number of room thermal control points
WATT.UNI	-Lighting-watts per sq. ft. (nominal)
OCCUPANT	-Design capacity
CONS.DAT	-Construction date-year
OCCU.DAT	-Occupancy date-year

C) Initial Costs (Numeric)

INI.ARCH	-Architectural-general contract including elevators
INI.HVAC	-Mechanical contract-HVAC
INI.ELEC	-Electrical contract
INI.PLUM	-Mechanical contract-plumbing
INI.SITE	-Site contract (not excavation)
INI.FURN	-Building equipment contract
PROF.FEE	-All professional fees

D) Operating Costs (FY 1968-69 through FY 1972-73)

CUST/68 etc.	-Custodial 1968-$/year
M.GEN/68 etc.	-General maintenance 1968-$/year
M.MEC/68 etc.	-Mechanical maintenance 1968-$/year
M.ELEC/68 etc.	-Electrical maintenance 1968-$/year
M.SITE/68 etc.	-Site maintenance 1968-$/year

E) Utility Costs (FY 1968-69 through FY 1972-73)

FUEL/68 etc.	-Oil or gas or steam-$/year
ELECT/68 etc.	-Electricity-$/year
UTILI/68 etc.	-Water and sewer-$/year
U.FUE/68 etc.	-Unit fuel cost-$/mil BTUs
U.ELE/68 etc.	-Unit electrical-$/mil BTUs

F) Other Information

DEGDAY68 etc.	-Degree days-65^{o} F. base
GSA.R/68 etc.	-GSA cleaning rating
OCC.%/68 etc.	-Percent of design occupancy for year

Information on thermal characteristics of glass, walls and roofs and capital improvements was not consistently collected and in effect, not included in this study. General comments on data availability are included in Section 4.3 of this report.

5.3 DATA BASE - STATE LEASE INFORMATION LANSING

The Bureau of Facilities presently has a computerized system for monitoring the State's leased space. Consequently, the information on leased space is readily available. The objective of including this information in the data base was to make the information available in the same form as that obtained from the other data base for economic analysis and futher illustrates the availability of information retrieval.

Development of the data base was relatively simple as it was only a problem of re-coding the information from computer printout. In those cases where the State provides maintenance such cost should be added.

The following parameters were identified for the 118 leases in the Lansing area:

LESSOR	-Name and code
AGENCY	-Agency occupying space and code
OPTIONS	-Renewal option and code
INTERVL	-Interval of renewal and code
ESCAPE	-Escape clause-and code
OCCUPAN	-Occupancy type and code
COUNTY	-Coded value
FLO.AREA	-Gross sq. ft.
RENT/ANN	-Annual rent total $
LEASE#	-Lease number
STRT/MO.	-Month of lease start
STRT/YR.	-Year of lease start
STOP/MO.	-Month of lease termination
STOP/YR.	-Year of lease termination
NOTICE	-Days of notice for cancellation
ESCAPE	-Escape clause code only
HEAT	-Provision by lessor or State
ELECTRIC	-Provision by lessor or State
UTILITY	-Provision by lessor or State
JANITOR	-Provision by lessor or State
BG/MAINT	-Building maintenance-lessor or State
GR/MAINT	-Grounds maintenance-lessor or State
SNOW	-Snow removal-lessor or State
PARKING	-Number of cars

.4 USE OF COMPUTER INFORMATION SYSTEM

The computer information system program cited in several places in this report was used in the demonstrations and is available for further study of the two data bases described in this report. Essentially the computer program is used for

1) information retrieval with a subsetting capability

2) arithmetic operations and data comparison

3) multiple regression analysis.

The quality of data and the system of processing the data are both fundamental in the total information system. But equally important will be the study of the information system, i.e., identifying the problem to be solved and developing the strategy for its solution. The samples of information retrieval included in the appended report and in Figure 9 are used in comparing information and in identifyir the best subset of buildings that can be used as a source of information for the regression analysis. Identification of the more significant independent variables depends on the knowledge of logical relationships, specific results from prior regression analyses and, of course, available stored information.

Figure 10 illustrates the results from a regression study attempting to develop a model for predicting the initial building costs.

Figure 11 indicates a projection of costs for a set of buildings. This assumes amortization of equivalent 1973 initial building cost over a period of 30 years at 5.25 percent annual interest. Models were developed for each of the categories and values listed are estimates based on these models. It should be noted that where missing information (refer to Section 4.3) occurs that particular value is an independent forecast for that building as it was not used to develop the equation.

Life Cycle Cost Budgeting - Example

During the course of this study the Bureau of Facilities started construction of an office building in the Secondary Governmental Complex in Lansing. A construction management firm was employed with the project bid and scheduled using the "Fast Track" method. Information available for this study consisted of preliminary design drawings with plans and elevations along with an outline specification. The C.M.'s estimates were used as a comparison of initial costs for site, professional fees and equipment.

	SUBSET INI.BLDG	DEFAULT SET FLO.AREA	BLDG.TYP	ARCHITEC
ADMINISTRATION	2514000.000	79107.000	OFFICE	ALDEN DOW
BUSINESS ADMIN.	2715000.000	136485.000	OFFICE/CLASSROOM	BLACK & BL
DENTAL SCHOOL	13027533.000	307156.000	CLASSROOM/OFFICE	SMITH HINC
INST. SOC. RSRCH	1638799.000	81623.000	OFFICE	ALDEN DOW
LSA	2082389.000	126092.000	OFFICE	HARLEY ELL
MODERN LANGUAGES	4423000.000	127405.000	CLASSROOM/OFFICE	ALBERT KAHN
MUSIC SCHOOL	2625353.000	110000.000	CLASSROOM/OFFICE	SAARINEN
PHYSICS & ASTRON	2753941.000	129669.000	CLASSROOM/OFFICE	ALBERT KAHN
PUBLIC HEALTH	6207835.000	169597.000	OFFICE/CLASSROOM	ALBERT KAHN
ALLEN ELEMENTARY	622282.000	41425.000	CLASSROOM	EBERLE SMI
BADER ELEMENTARY	396344.000	24996.000	CLASSROOM	COLVIN&ROB
PATTENGILL ELEM.	663843.000	39299.000	CLASSROOM	LOUIS KING
FORSYTHE JR. HI.	1945129.000	114251.000	CLASSROOM	CHARLES LA
SCARLETT JR. HI.	3043993.000	156000.000	CLASSROOM	EBERLE SMI
LEWIS CASS BLDG	0.0	242000.000	CLASSROOM	SMITH HINC
STEPHEN T. MASON	5073488.000	253500.000	OFFICE	SMITH HINC
LAW BLDG	6316547.000	157445.000	OFFICE	SMITH HINC
STATE HIWAY BLDG	7058968.000	280000.000	OFFICE	SEDGEWICK
TREASURY BLDG	6481088.000	212000.000	OFFICE	SMITH HINC
SEC. OF ST. CPLX	2491635.000	120700.000	OFFICE	VALENTINE&
MANLY MILES	678393.000	58304.000	OFFICE	LEWIS SARV
STUDENT SERVICES	2622353.000	117309.000	OFFICE	CALDER & A
HANNAH ADMIN.	5113377.000	157850.000	OFFICE	CALDER & AS
BAKER HALL	1493168.000	59872.000	OFFICE	EBERLE SMI
SOUTH KEDZIE	2039910.000	71025.000	OFFICE/CLASSROOM	HARLEY ELL

Trial Data Set
Sample Retrieval of
Stored Information

Figure 9

```
 R SDY8:INFOSMAL# 8=SEBB:HISTDAT# 7=-FIL 0=-FOU
#EXECUTION BEGINS


  INFORMATION SYSTEM PROGRAM
 U.OF MICH.--DEPT.OF ARCH.
 BY DR.JOHN F. WILLIAMS
 REVISED JAN. 25,1974


  DO YOU HAVE A NEW DATA STRUCTURE...? NO
    ENTER USER CODE

    ?  REFR.TYP MAXIMUM = 4 MINIMUM = 1

    ?  FOUN.TYP MAXIMUM = 4 MINIMUM = 1

    ?  INI.HVAC MAXIMUM = 2000000 MINIMUM = 1

    ?  FOR TEST-INITIAL

    ?  ACTIVE TE ST-INITIAL

    ?  DEPENDENT VARIABLE INI.BLDG

    ?  INDEPENDENT VARIABLE FLO.AREA ROOFAREA FLOO.NUM CONS.  .DAT

    ?  REGRESSION

    ?  PRINT REG RESULTS


 DEPENDENT VARIABLE:     INI.BLDG

 NUMBER OF OBSERVATIONS:        13

 R:     .96682

 MEAN OF DEPENDENT VARIABLE:     3051940.00

 STANDARD ERROR OF ESTIMATE:      513482.62
```

INDEPENDENT VARIABLE	MEAN	STANDARD DEVIATION	REGRESSION COEFFICIENT	STANDARD ERROR	T STATISTIC
CONSTANT			-305938432.0000		
CONS.DAT	1963.31	5.5884	156315.4375	29848.9883	5.2369
FLOO.NUM	5.85	2.1543	-174531.0000	92052.1875	-1.8960
ROOFAREA	31983.46	23111.7070	-25.7787	8.8368	-2.9179
FLO.AREA	118150.81	53922.5273	33.3523	3.1699	10.5217

Sample use of --
Information System Program
- Regression Analysis

Figure 10

	SUBSET	SUMMARY		
	MAINSQFT	CUSTSQFT	UTILSQFT	COS1973U
ADMINISTRATION	0.267	0.186	0.692	42.782
BUSINESS ADMIN.	0.224	0.510	0.527	27.899
DENTAL SCHOOL	0.417	0.308	0.555	49.503
INST. SOC. RSRCH	0.312	0.497	0.803	40.434
LSA	0.210	0.464	0.570	42.755
MODERN LANGUAGES	0.179	0.250	0.590	38.696
MUSIC SCHOOL	0.214	0.377	0.578	43.760
PHYSICS & ASTRON	0.365	0.325	0.530	33.703
PUBLIC HEALTH	0.226	0.251	0.653	39.087
LEWIS CASS BLDG	0.413	0.622	0.595	33.592
STEPHEN T. MASON	0.332	0.554	0.512	34.796
LAW BLDG	0.281	0.456	0.962	44.210
STATE HIWAY BLDG	0.260	0.528	0.949	30.435
TREASURY BLDG	0.200	0.535	0.998	33.650
SEC. OF ST. CPLX	0.195	0.503	1.352	26.018
STUDENT SERVICES	0.126	0.286	0.857	39.034
HANNAH ADMIN.	0.160	0.336	0.859	33.407

	SUBSET	SUMMARY
	AMORT	ANNUCOST
ADMINISTRATION	2.862	4.007
BUSINESS ADMIN.	1.866	3.126
DENTAL SCHOOL	3.312	4.592
INST. SOC. RSRCH	2.705	4.317
LSA	2.860	4.105
MODERN LANGUAGES	2.589	3.608
MUSIC SCHOOL	2.928	4.096
PHYSICS & ASTRON	2.255	3.475
PUBLIC HEALTH	2.615	3.746
LEWIS CASS BLDG	2.247	3.876
STEPHEN T. MASON	2.328	3.726
LAW BLDG	2.958	4.657
STATE HIWAY BLDG	2.036	3.773
TREASURY BLDG	2.251	3.984
SEC. OF ST. CPLX	1.741	3.790
STUDENT SERVICES	2.611	3.879
HANNAH ADMIN.	2.235	3.590

COS1973U - 1973 Projected replacement costs
AMORT - Initial Cost - Amortized - 30yrs.
ANNUCOST - 1973 Total Owning Cost

Projected Costs Based on Regression Models

Figure 11

costs. In the cases of the latter three items the "master data base" was assumed to be insufficient for use for this trial study.

The study of the proposed office building consisted of projections for initial costs and Life Cycle Costs as well as present worth comparison of an alternative strategy of providing higher lighting levels.

General Comments

Many limitations are imposed upon this study by the scope of the trial "master data base". Study of the entire group of buildings indicates a strong relation between air conditioned buildings and life cycle costs. Seventeen (17) buildings are air conditioned. Further, size appears to be an important factor for certain of the costs, consequently, buildings under 100,000 sq. ft. were eliminated for studies of utility costs and energy consumption. In so far as possible, there was an attempt in modelling to obtain a compatible set of buildings as a base for the forecasting.

Several characteristics of the building are unique in reference to the data base. The building although large, 259,300 sq. ft., has a large ratio of envelope and glass area to floor area. For example, it has twice as much glass and 70% more wall area than the Treasury building, 212,000 sq. ft. The projected building does use double glazing, a feature unique to the subset available for energy studies. Landscape office space is also unique to this building. The use of central heating is common, although the use of central chilled water supply is unique. The major concern, however, is in the policy changes in reaction to the energy crisis. The change in lighting levels is identifiable and is the subject of this alternative study.

Regression Analysis

Regression models have been developed for each of the eight dependent variables noted in Figure 12. The independent variables, their values for the new building and the respective regression coefficients are noted for each model. The mean of the dependent variable and the the standard error of the estimate are also noted. Other

MODEL NO.	DEPENDENT VARIABLE	NO.	MEAN (STANDARD ERROR)	INDEPENDENT VARIABLE	SECONDARY COMPLEX-OFFICE	REGRESSION COEFFICIENT	MODEL ESTIMATE
100	INI.BLDG (Total $)	17	$3,624,365. ($ 575,639.)	FLOO.NUM	3 (no.)	-388284.	
				CONS.DAT	1973 (yr.)	+141473.	
				ROOFAREA	86,780 (sq.ft.)	-38.6282	
				WALLAREA	83,690 (sq.ft.)	+28.6202	
				FLO.AREA	259,300 (sq.ft.)	+24.7591	
				CONSTANT		-275360000.	$8,064,481.
101	INIARCH (Total $)	17	$2,161,033. ($ 372,672.)	FLOO.NUM	3 (no.)	-149938.6	
				CONS.DAT	1973 (yr.)	+70686.9	
				ROOFAREA	86,780 (sq.ft.)	-17.2848	
				WALLAREA	83,690 (sq.ft.)	+10.0157	
				FLO.AREA	259,300 (sq.ft.)	+10.9993	
				GLAS.ARE	30,830 (sq.ft.)	+29,53337	
				CONSTANT		-137,533,872	$5,492,971.
102	INI.MECH (Total $)	12	$1,358,100. ($ 217,674.)	MECH.ZON	129 (no.)	+3370.68	
				WATT.UNI	2.0 (watts/sq.ft.)	+393412.2	
				GLAS.ARE	30,831 (sq.ft.)	-9.4038	
				FLO.ARE	259,300 (sq.ft.)	+4.5189	
				CONSTANT		-1216818.0	$1,466,509.
03	INI.ELEC (Total $)	15	$381,769. ($ 93,470.)	LIGH.ZON	250 (no.)	+390.9739	
				FLO.AREA	259,300 (sq.ft.)	+3.2743	
				CONS.DAT	1973 (yr.)	+19883.2	
				CONSTANT		-39239376.0	$936,947.
04	CUST/72 CUST/71 CUST/70 (Annual $)	48	$66,411. ($14,987.)	OCCU.DAT	1975 (yr.)	+203.22	
				INI.ARCH	5,492,971. ($)	-0.0150	
				ASSIG.AR	215,930 (sq.ft.)	+0.9716	
				CONSTANT		-392303.8	$136,459.
105	M.BLDG71 M.BLDG72 (Annual $)	28	$31,198. ($ 7,098.)	ROOFAREA	86,780 (sq.ft.)	-0.2617	
				FLO.AREA	259,300 (sq.ft.)	+0.4934	
				WALLAREA	83,690	+0.3808	
				INI.BLDG	8,064,481. ($)	-0.0099	
				OCCU.DAT	1975 (yr.)	+1103.1851	
				CONSTANT		-2176998.	$59 052.
06	U.TOT71 U.TOT72 (Annual $)	20	$134,195. ($ 10,480.)	MECH.ZON	129 (no.)	+61.5589	
				DEGDAY	6,840.5 (deg.days)	+176.4481	
				WATT.UNI	2.0 (watts/sq.ft.)	+18322.691	
				GLAS.ARE	30,830 (sq.ft.)	-2.0593	
				ASSIG.AR	215,930 (sq.ft.)	+0.2849	
				WALLAREA	83,690 (sq.ft.)	+0.1921	
				OPYEAR	4 (yrs.)	+8439.977	$144,666.
07	ENER/71 ENER/72 (MIL-BTUs) per year)	20	$99,780. ($ 5,095.)	MECH.ZON	129 (no.)	+119.2965	
				DEGDAY	6,840.5 (deg.days)	+44.3282	
				WATT.UNI	2.0 (watts/sq.ft.)	+15361.808	
				GLAS.ARE	30,830 (sq.ft.)	-1.0390	
				ASSIG.AR	215,930 (sq.ft.)	+0.4025	
				WALLAREA	83,690 (sq.ft.)	+0.1129	
				CONSTANT		-308269.	105,398 MIL-BTUs

REGRESSION MODELS
1973 - OFFICE BUILDING - SECONDARY COMPLEX

FIGURE 12

statistical measures of the model are included in the computer printout in the addendum report. Independent variables were selected to give the best statistical fit as well as to include the parameter that was to be a subject of the comparison. In the latter case if such were not significant it was not included. Thus WATT.UNI (watts of lighting per sq. ft.) was only included with Model 102 (INI.MECH), Model 106 (UT.TOT72 - Utility) and Model 107 (ENER/72 - total at source energy).

Initial cost estimates were based on year 1973 and operating costs on occupancy in FY75-76. The following comparisons are based on the model estimates noted in Figure 12.

SECONDARY COMPLEX - OFFICE

LIFE CYCLE COST FORECASTS

I Comparisons - Initial Costs

		(Regression Model)	(Actual or Estimate)
A.	Total Building	$ 8,064,481	$ 8,196,802
B.	Architectural	5,492,971	5,416,338
C.	Mechanical	1,466,509	2,082,388
D.	Electrical	936,947	698,076
E.	Total (B+C+D)	$ 7,896,427	
F.	Site	(model not available)	863,560
G.	Professional fees	(model not available)	785,223
H.	Equipment (Furn.)	(model not available)	1,131,000
J.	Total Project Estimates (A+F+G+H)	$ 10,844,264	

II Life Cycle Cost - Projections for FY75-76

A. Amortization (assume 30 years @ 5 1/4% - bond equivalent)

Annual Cost = $2.75/sq. ft.

B. Building operation; custodial + maintenance + utility

Annual Cost = $1.30/sq. ft.

C. LCC FY75-76 = $4.06/sq. ft.

D. At source energy budget - 406.5 MBTUs/year/sq. ft.

III Comparison of Alternatives -

Present worth - 30 years Life @ 5.25% interest

Assume 2% inflation factor for custodial and maintenance with a 4% factor for energy.

A. Alternative 1

Design condition of 2.0 watts/sq. ft., nominal lighting.

Present Worth Summary

(All values are for a square foot of gross floor area)

Initial project cost	$ 41.82
Custodial and maintenance	13.96
Utility	12.27
Total owning costs	$ 68.05/sq. ft.

B. Alternative 2

Same as 1 except lighting increased to 4.7 watts/sq. ft. as per design conditions in the main complex (computations not shown)

Initial project cost	$ 45.26
Custodial and maintenance	13.39
Utility	16.47
Total owning costs	$ 75.12/sq. ft.

The energy budget would increase to 566 MBTUs per sq. ft.

The model estimates for the total initial building and initial architectural costs are very close to those of actual project, whereas estimates for mechanical and electrical are off considerably. The latter may be due to earlier noted desparities between the new building and the data set. However, it does indicate that more descriptors are needed to more adequately account for these contract specialities.

Projection of annual operating costs are based on three years of data for custodial and two years for maintenance and utility costs. Three agencies are involved in the custodial model, whereas only two agencies are included in each of the other two models. The best model was achieved for the total at source energy projection in that the standard error of the estimate is approximately $\pm 5\%$. At source energy involves the conversion of utility costs to available energy with electrical energy multiplied by

3 to account for central power plant efficiencies. A further use of Model 107 is illustrated in the next section in a study of the Treasury building.

The comparison of alternatives noted in item III uses the regression models to study the effect of a hypothetical decision to increase the lighting level to that previously used with the inflation factors noted. The $7.07 difference in owning cost is in effect the 30 year cost of providing double the lighting levels. This would be equivalent of $900 per employee. The projected energy budget of 566 MBTUs/ sq. ft. does represent a very significant increase from the 406 MBTUs for the lower light levels.

In conclusion it should be noted that no land costs or projected capital improvement costs have been taken into account. However, the study should be useful in identifying the relative importance of the several cost factors in the total life cycle of a building.

5.5 ENERGY ANALYSIS AND COMPARISON

One of the several functions of the data center would be that of providing information on computer software packages available for use by the agencies, or in response to specific needs identify sources of required information.

During the course of this study the staff has been appraised of the many efforts the Bureau of Facilities has undertaken to identify energy conservation methods. These include a study of the feasibility of computerized control of the mechanical equipment to supplement the existing centralized monitoring system for the Central Government Office Complex. Because of this concern as well as that of illus rating another form of modeling for the use of forecasting the energy factor in life cycle costs, the following computer analysis and evaluation are included in the demonstration studies.

The computer program used in this simulation study is currently available to the U of M architectural student for comparative thermal analysis in their design projects The results of the program as well as the algorithms have been checked in the past by means of analysis of several major buildings. Several of the algorithms were developed in conjunction with the writer's earlier consultation with Smith, Hinchman and Grylls Associates. Despite the extensive checking, the programs still should be considered experimental. However, as they have been energy-life-cycle oriented from the early development, they are appropriate for this demonstration and subsequent use by State Agencies for comparative studies.

The following steps were involved in carrying out this study:

1) Procuring a magnetic tape of Lansing Weather Bureau data from the National climatic Center in Asheville, N.C. The tape includes 3 hourly surface weather observations for the period 1965-72. The tape is stored at the U of M computer center and is available for remote mounting and reading.

2) Read and interpret the data and prepare a simulation-year file for the Lansing area. The fiscal year July 1, 1971-June 30, 1972 was selected for this particular study. These first two steps are only required to initialize data for the Lansing area and would not, of course, be needed for other studies in Lansing.

3) Assemble a data file on the specific building characteristics using the A/E drawings provided by the Bureau of Facilities. This file is identified as "BLDG" in the compendium report of computer printout. An interactive program is used to assist the user in organizaing the data. Variables A-E, as noted in Figure 13, have been considered in this step.

4) Assemble a data file on system information. File "THER" contains this information. Variables E and G are identified by this step.

5) Run the two analysis programs, i.e., on walls and systems. Output from these are included in summary form in file "THER". Detail output for each of the 360 hours considered are included in files "WALL", "ROOM", and "SYST", as noted in the compendium report. These files are presently stored on tape and could be selectively retrieved for comparative studies on the specific building.

6) Analyze and summarize the results comparing same with metered data for the same fiscal year. Assumptions and comparitive results are included in Figure 13--16.

A. Glass Wall Areas

   1. External Shading of Glass

   2. Type of Glass - Transmission, "U" Value

B. Opaque Wall Areas

   1. Composition by component - Thickness, Denisty, Conductivity, and Specific Heat

   2. Reflectivity of Surface

   3. Position

C. Room Definition

   1. Wall Areas and % of Glass

   2. Lighting Systme - Walls, Cavity, User Pattern

   3. Activity - Sensible and Latent Heat, User Pattern

   4. Infiltration - Winter and Summer

D. Zone Definition - Combination of Rooms

E. Sector Definition - Combination of Zones

F. System Factors

   1. Ventilation - Amount and System Location

   2. Air Supply Criteria - Temperature Differences and Limits

   3. Percentage of Lighting Heat Entering Space

   4. Air Handling Units - System Location

      - Minimum or Variable Outside Air

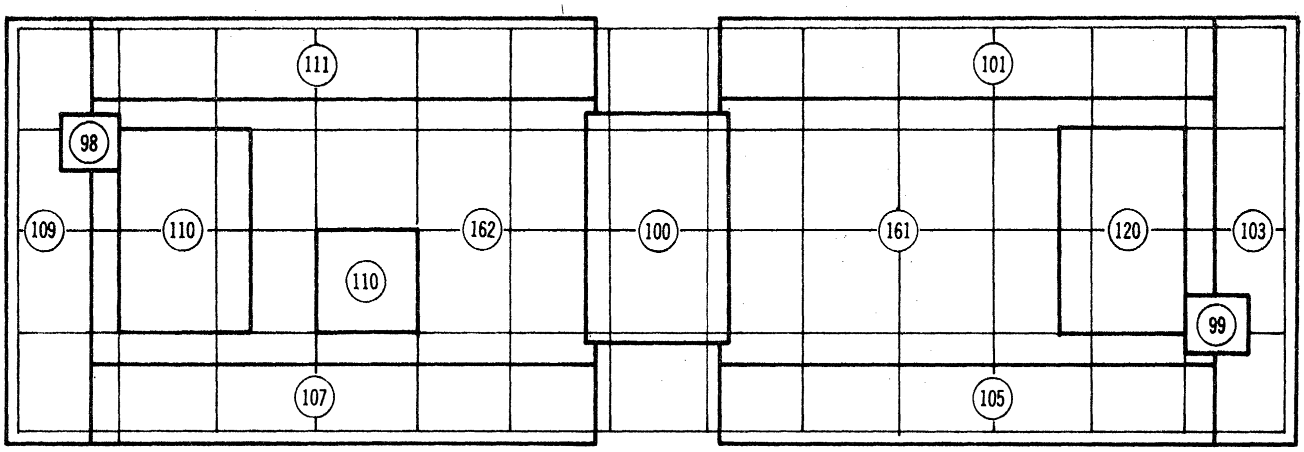
      - Bypass or Reheat

G. Design Conditions DB and RH Lows and Highs

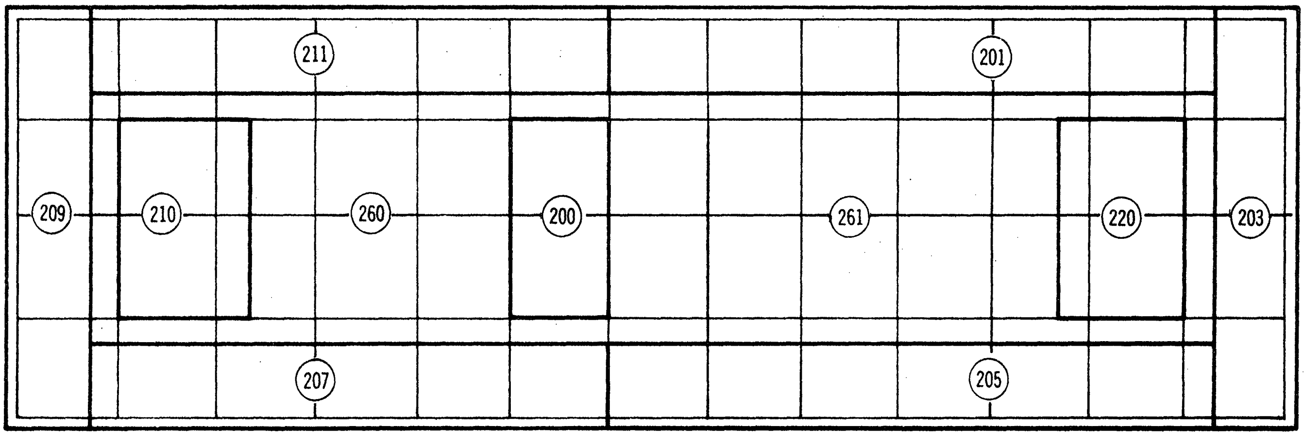
H. Climatic Variables - (selection of a local simulation year file). Analysis for 36 prototype days and 10 intervals each. Wind speed, AM and PM sunshine, DB and DP for each interval.

TREASURY BUILDING
THERMAL SIMULATION - Variables Considered

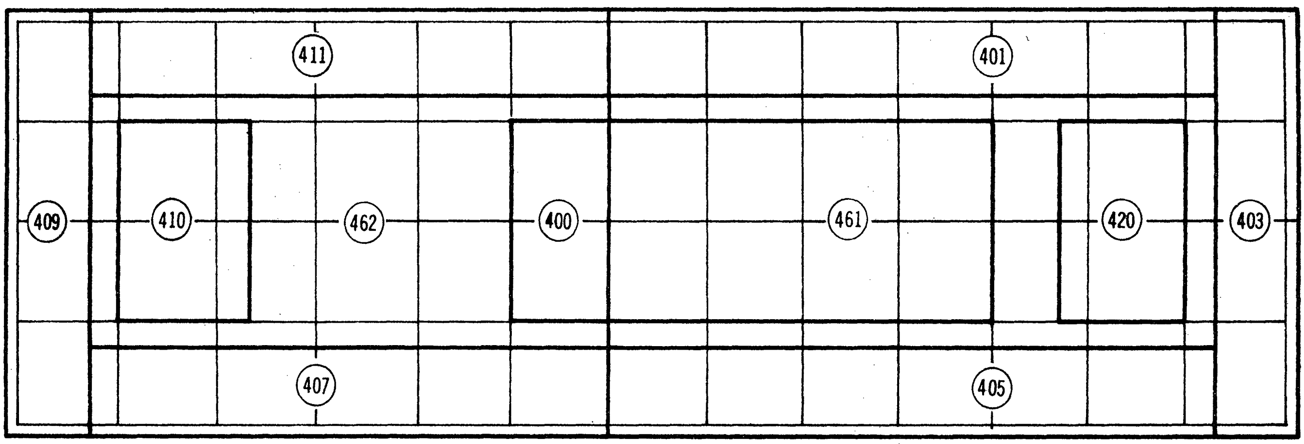
FIGURE 13



first floor



second/third floor



fourth floor

STATE TREASURY BUILDING

Figure 14

III

		Load KW	Operation Hours/Year	Energy M -BTUs/Year	
A. Electrical Consumption					
1. Lighting:	Sect. 1	496.8			
	Sect. 2	387.0			
Subtotal		883.8	3443	10,345.0	
2. Lighting + Computer					
	Sect. 3	177.0	4992	2,739.0	
3. Air Handling Motors		390.0	4992	6,641.0	
4. Pumps, Heating, etc.		124.6	7653		2,868.0
5. Refr. - Bldg.		41.0	2007		280.0
6. Refr. - Computer		41.0	4992		689.0
Total					23,661.0
7. Elevator*					

B. Steam

Heating		----	Simulation	38,113.0
Cooling: (Absorption)	Sect. 1	4083×10^6 BTUs/yr		
	Sect. 2	3509×10^6 BTUs/yr		
Subtotal		7592 x 1.8 (eff.)		13,669.2
Total				51,782.2

* Elevator power was not included as the specific characteristics were not available at the time of the study.

TREASURY BUILDING
THERMAL SIMULATION - Detail Supplement

FIGURE 15

ITEM	SIMULATION	ACTUAL(71-72)	SOURCE
I Supply Air			
Sect. 1	105,943		
Sect. 2	85,639		
Total	191,582 CFM	217,700 CFM	Owner's Data
II Cooling Loads			
Sect. 1	5,567,809		
Sect. 2	4,586,372		
Total	10,154,598 BTUs hr.		
	or 846 tons	900 tons	Owner's Data
III Energy FY 1971-72			
A. Electrical*	23,661 x 10^6 BTUs/hr	27,883 x 10^6 BTUs/yr	Metered - (Historical Data File)
B. Steam	38,113 x 10^6		
Heating	38,113 x 10^6		
Cooling (Absorption)	13,669 x 10^6		
Total	51,782 x 10^6 B Us/yr	54,160 x 10^6 BTUs/yr	Metered - (Historical Data File)

*NOTE: Electrical energy has been identified in BTUs/yr rather than the conventional KWHR/YR

TREASURY BUILDING
THERMAL SIMULATION - Summary

FIGURE 16

The Treasury building was chosen for this study principally because of Bureau's interest and the available data. Fiscal year 1971-72 was chosen to permit the use of corresponding Weather Bureau data and to eliminate the effect of policy changes in FY72-73 which would have complicated the comparison. The results of the comparison in regard to energy consumption are relatively close and was the result of a "first cut" on assumptions.

The following example of the effect on energy consumption by reducing lighting by an average of approximately 40% throughout the building is included to illustrate the use of the models as well as to compare the regression and simulation models.

The simulation of the modified thermal model involved change of the unit-watts values in each of the rooms in file BLDG, and rerunning of program AIRSYST. Values for the entire revised system are included in the files in the appended computer output. It should be noted that this change only involved rerunning the last of the four programs.

Simulation comparisons using FY71-72

(all values BTUs/year)	Original	Revised
Electrical	$23,661 \times 10^6$	$20,661 \times 10^6$
Steam (including cooling)	$51,782 \times 10^6$	$50,076 \times 10^6$
Total at Source Energy	$122,765 \times 10^6$	$112,059 \times 10^6$
or	579×10^3/sq.ft.	528×10^3/sq.ft. (approximately 10% saving)

Regression Model 107, Figure 12, was used for the same comparison. The unit WATT.UNI used in this comparison was consistent with the average value used in the thermal simulation, i.e., 4.16 and 2.69 watts.

Applying the appropriate values for each of the parameters noted in Model 107, Figure 12, the following results are obtained:

	Total at Source Energy
Design situation	$136,406 \times 10^6$ BTUs/year
Lower Light Level	$113,824 \times 10^6$ BTUs/year (approximately 16% saving)

The energy saving impact of reducing lighting levels can be estimated to be between 10 to 16%, the range between the two methods.

Models such as these can be used to identify some of the parameters for the historic data base. It should be noted, however, that the Treasury building is relatively unique in that the factors affecting energy consumption might be considered deterministic from the view of forecasting within a limited time frame. From the broader view of life cycle costing, stochastic events such as the change in policy toward energy conservation, need to be identified and considered for effective forecasting.

.6 SYSTEM DEMONSTRATIONS

One of the principal conserns in exploring strategies for implementation of LCC is that of involvement of staff in the research. As part of this process several demonstrations have been scheduled. The following statements are intended as summary of each.

A) December 27, 1973: Lansing at Bureau of Facilities. Attendance: Bureau of Facilities - Messrs. Durkee, Sullivan, Leeley, Hawes, and Roege; Bureau of Management - Mr. Ripley; University of Michigan - Messrs. David, Shimizu, Oberdick. Scope and problems involved in collecting data for the 25 buildings were discussed in some detail. The data structure for the files were described along with the logical structure for accessing U of M-M.T.S. with the State's NCR-260 terminal. Demonstration involved the use of Information System Program for information retrieval and data comparison.

B) January 11, 1974: Ann Arbor. Attendance: Messrs. Wendell and Mayer, U of M Plant Department - by W. Oberdick. Discussed objectives of the research with particular emphasis on the historic data file and its possible use in LCC. Demonstration involved retrieval of information on U of M buildings.

C) January 22, 1974: East Lansing. Attendance: Messrs. Simon, Flinn and Coon of MSU Plant Department. Discussion and demonstration similar to that of U of M except MSU buildings were used.

D) Demonstration and discussion with the Bureau of Facilities, Management Division, William Hawes, Chief. Agenda:

1. Brief description of LCC objectives
2. Use of U of M-M.T.S. via NCR 260 terminal
3. Discussion of Treasury Building Simulation
4. Identification of the Divisions of 1974 Energy Strategy and prediction of its impact
5. Use of historic data and lease data files
6. Comparison of lease data and life cycle cost of the new Department of Health Office building.

E) Demonstration and discussion with the Bureau of Facilities, Design Division, Ralph Seeley, Chief and the Construction Division, William Roege, Chief. Agenda:

1. Brief description of LCC objectives
2. Use of U of M-M.T.S. via NCr 260 terminal
3. Use of historic data base for modeling
4. Economic analysis, LCC of state office buildings
5. Discussion of performance measures
6. Needs

F) Summary discussion with management groups of Bureau of Facilities. Agenda: to be determined by Bureau of Facilities.

6.0 APPENDICES

6.1 COMPUTER-OUTPUT - SUMMARY OF ADDENDUM TO REPORT

The Addendum to Report consists of

1) listings of comparative data from the information system regression studies

2) files used to support the information system

3) listings of files representing detail output from the thermal analysis programs for the Treasury building.

INDEX

	Pages
A) Building Information System	
1. Use of information system with master data base - sample runs	1-6
2. Regression models - concluding runs supporting models in Figure 12	7-18
3. Projections from regression models - including listings of commands to use the arithmetical operators of the system	19-25
4. Listings of variables and reference codes.	26-32
5. Master data file - historic data on 25 buildings, 119 numeric parameters, 20 alphanumeric parameters	32-41
6. Use of information system with lease data base	42-a
7. Master data file - lease data for State offices in Lansing	42-54
8. Sample file from a user's data base listing of commands and interpreted files	55-65
9. Use of information system with a cost index data base*	55-69
B) Thermal Simulation	
1. Summary instructions for use of Thermal programs	71a-n

* NOTE: Cost index data base developed on the project. Further detail has not been included in this report.

	Pages
2. Sample teletype output for System Analysis - step 4	72
3. File BLDG - a listing of thermal description of the building - step 1	73-82
4. File THER - a summary listing of thermal output from step 2, 3 and 4	82-86
5. File WALL - a detail listing of "hourly" gains and losses for transparent and opaque components for each of the identified walls noted in FILE, BLDG, and THER - step 3	86-92
6. File ROOM - a detailed listing of "hourly" gains and losses for each identified room; Sensible, latent and delayed heat are separately identified	92-128
7. File SYST - a detailed listing of "hourly" conditions anticipated in each of the air handling zones - step 4	128-142

The following files are similar to those noted above except as they correspond to change in lighting levels for the comparative study.

8. File BLDG	143-152
9. File THER	152-156
10. File WALL - duplicate of listing in item B(5)	157-162
11. File ROOM	162-198
12. File SYST	198-212

6.2 POSITION STATEMENTS

As noted in the report, reviews of applicable analytical tools and related subjects were prepared during the course of the study. These are listed for reference without comment.

Probability and Statistics - Mathematical Programming: Applications for Building Cost Analysis

John Williams

Review of Simulation Models as an Analytic Tool

Kaien Shimizu

Building Benefit: A Logical Structure for Applications

John Williams

Geographical Segmentation of Michigan for Locational Basis For Statistical Cost Forecasts

George Birrell

PROBABILITY AND STATISTICS - MATHEMATICAL PROGRAMMING: APPLICATIONS FOR BUILDING COST ANALYSIS

Economic and cost/benefit analyses have historically been an integral part of the building planning and design process. Each implies a distinct level of consideration. Economic studies suggest a concern for the financial needs of the client as they relate to the economic impact of a promect on local and regional communities. Alternatively, cost/utility measures are evaluated with the objective of minimizing project resource allocations while obtaining the maximum derived benefit. Although much attention is apparently given these subjects, it belies the existing capacity to respond, systematically, to the critical issues raised. The pattern has generally been one of intuitive exploration, often supported by common economic techniques, i.e., discounting present value, cash flow, etc. This approach is useful but neither sufficient nor complete. The principal deficiencies are, first, an inability to extract consistent relationships from data describing past experience and, secondly, the absence of a rational method for incorporating the uncertainty of stochastic events in the decision process. With the advent of large scale digital computers, it is now feasible to, in part, resolve this condition through selective application of concepts associated with probability and statistics and mathematical programming. Using these techniques, predictive models can be formulated which, if carefully developed and implemented, may offer the design professions and facility owners an opportunity to conduct experiments examining both broad community based and building specific economic implications.

Many volumes have been devoted to exploring and presenting the theory of probability and statistics. The discussion here is limited to those aspects of theory and practical application which directly relate to constructing predictive building cost models. For this purpose, it is reasonable to describe probability as a method for quantitatively incorporating the uncertain occurrence of events, over which no control may be exercised, into the forecasting model. The events or variables to be considered must exhibit some degree of regularity, such that the frequency of occurrance can be defined using a probability distribution. For example, each year student enrollment at a university changes. Historical records show the frequency of increases and decreases for the past 10 years to be:

Number of Occurrences	Level of Change
4	100
2	300
3	500
1	800
10	

To anticipate next year's enrollment, using this information, a probability distribution is formulated:

$$P_1(100) = 4/10 = .4$$
$$P_2(300) = 2/10 = .2$$
$$P_3(500) = 3/10 = .3$$
$$P_4(800) = 1/10 = .1$$
$$1.0$$

This states that the probability of an enrollment increase equalling 100 is .4, etc. It may be noted that the vector of probabilities, P, always sums to one. It is further stated that an increase will occur only if personal income rises during the preceding year, then a prior conditional probability exists as follows:

$$P_5(\text{personal income increase}) = .8$$
$$P_6(\text{no personal income increase}) = .2$$

The previous distribution must then be adjusted to reflect the possibility that no enrollment increase will occur next year as follows:

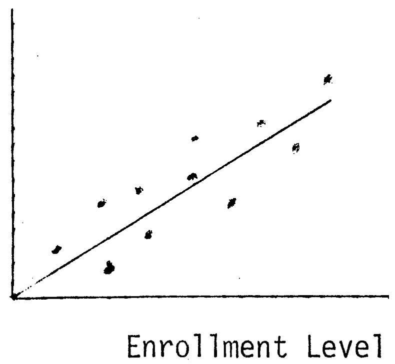
$$P_1(100 \ 1 \text{ year } n) = (.8)(.4) = .32$$
$$P_2(300 \ 1 \text{ year } n) = (.8)(.2) = .16$$
$$P_3(500 \ 1 \text{ year } n) = (.8)(.3) = .24$$
$$P_4(800 \ 1 \text{ year } n) = (.8)(.1) = .08$$

If each potential value is multiplied by the associated probability and a summation performed, the result is an expected value of measure of the anticipated outcome:

E(enrollment increase In) = (.32)(100) + (.16)(300) + (.24)(500) + (.08)(800)

Using expected value is risky in that is rarely reflects actual conditions. Other, preferred decision techniques will be explored in a later section. One need not rely exclusively on historical data to formulate distributions. The initial vector, P, could, as well, have been defined through an intuitive procedure and the values would thus be described as subjective probabilities. Clearly, then, probability theory does offer a convenient and effective means of formally treating uncertainty.

In contrast with the concept of probability, for which the absence of data does not proclude formulating a distribution, the existence of an information set is implicit in a statistical analysis. Statistical techniques are applied to reduce several values of one variable to a single, independent descriptive measure, i.e., mean, standard deviation, etc., or to develop mathematical relationships between two or more variables. In either case the intent is to confirm or deny a hypothesis or theory passed upon available information. A useful method of defining the correlation between two elements is least square regression analysis. Extending the previous example, an hypothesis is constructed which suggest that a linear relationship exists between the level of student enrollment and the cost of operating university buildings. Data for each variable has been collected and plotted.



A regression model, or mathematical description of the relationship is formulated as follows:

$$C = b + b_1x_1 + E$$

where:

C = estimated cost of operation

b = constant

b_1 = coefficient

E = residual

x_1 = enrollment level

The regression operations will yield values for b, fixed operating cost not affected by enrollment level, and b_1, unit increase in operating cost attributable to a unit change in enrollment. x_1 is the independent or estimating variable upon which the operating cost, C, is dependent. Since the equation represents line B-B on the plot and, obviously, all data points are not on that line, the E term measures the residual or error in each estimate. Having derived a relational model, the potential now exists for linking it to the established probability model, which predicts values of enrollment x_1, and forecasting next year's operating cost. It may be noted that such models are not limited to one independent variable, but can define the simultaneous relationships of many factors. Other techniques such as analysis of variance and Bayesian statistics are used for similar purposes, the principal concern of the latter being the size and state of all the possible data, or "population", and the nature of the available data, or "sample". In any case, patterns and relationships which cannot be perceived through direct observation of the data can be established mathematically.

To this point, the concern has been one of describing events, conditions, and relationships with abstract models. The logical sequence is, then, to pose the question of how such models can be incorporated in a process to arrive at the "best" decisions. The response is a group of methodologies generally referred to as mathematical programming. By name, they are linear programming, network analysis, dynamic programming and game theory. Several characteristics are common to each technique. First, it is assumed that both costs, in the generic sense, and benefits or rewards can be estimated for a finite set of system states, i.e., models can be constructed to anticipate these values. Secondly, for each state, or set of conditions, a decision strategy can be formulated which will determine the subsequent state. Finally, there exists some optimum strategy with regard to all sequential system states. These criteria are certainly satisfied for many facility planning and design activities. However, applying the techniques directly is a complex task and very little research has been performed to demonstrate potential uses with the exception of network analysis which has resulted in the PERT and CPM methods. As those two are widely known, only linear and dynamic programming and game theory are reviewed here.

Linear programming is a procedure for solving problems which can be represented by a series of simultaneous equations. Optimization is achieved according to an objective function and controlled by constraint relationships. For example, assume that data has been collected describing the quantities of n space types and total costs for M sample buildings. To allocate the total costs among the various spaces, the following linear model could be formulated:

objective function:
minimize $D = g_1 A_1 + \ldots g_n A_n - T$

constraints

building 1 $\quad a_{11} x_{11} + \ldots\ldots a_{1n} x_{1n} = T_1$

" "

" "

" "

" "

building m $\quad a_{m1} x_{m1} + \ldots\ldots a_{mn} x_{mn} = T_m$

where:

T = total cost of all sample buildings

T_i = cost of sample building i, for i = 1,m

A_j = total space type j, for j = 1,m

x_{ij} = space type j for building i

g_i = computed cost per unit of space type i

a_{ij} = cost per unit of space type i in building j

D = difference between actual and computed cost

The objective is to find coefficients in vector G, representing the per unit cost assigned to each space type, which, when multiplied by the total quantity of each space type, yield the minimum variance from the actual total cost, T, subject to the constraint equations.

Dynamic programming refers to a general class of models characterized by sequential system states, having a series of alternative associated with each step. In essence, the problem is considered as a set of sub-problems, the optimal solution of which leads to a "best" strategy for the total. For example, consider the previous case where annual university operating costs are a function of the enrollment level. Now, assume that the university derives some non-linear benefit from an increase in enrollment, say a progressive state formula. Further, the university can, to some extent, control enrollment by a policy which permits three levels the first year, four during the second and two during the third. The alternatives over a three year period can be described as follows:

	2	3	4
1	n_1	n_2	n_3

	5	6	7	8
2	n_4	n_5	n_6	n_7
3	n_8	n_9	n_{10}	n_{11}
4	n_{12}	n_{13}	n_{14}	n_{15}

	9	10
5	n_{16}	n_{17}
6	n_{18}	n_{19}
7	n_{20}	n_{21}
8	n_{22}	n_{23}

	11
9	n_{24}
10	n_{25}

The values contained in the vector N represent the net gain or loss associated with going from the row state to the column state. For example, each n_i is the difference between increased revenue allocations and the rise in operating cost associated with larger enrollments. Dynamic programming will develop an optimal three year enrollment strategy by examining the problem in three stages, from right to left, defining the best decision at each node, given the existing results from each prior calculation.

Game theory, although frequently used to reference operational gaming, may be strictly interpreted as a method for resolving a "2-person zero-sum" situations. Such games involve only two adversaries, or players, and what one wins the other must lose. To consider a simple example, assume that an institution wishes to acquire additional facility space and has the option of leasing or building. The players are the institution and a second entity with space available for lease. The following "payoff table" is developed:

			Leasing Entity: renew 1	Leasing Entity: cancel 2
Institution	lease	1	+5	-5
Institution	build	2	0	0

The lease must run for five years at a prescribed rate of 9 units. Amortizing construction costs over a twenty year period, the institution's annual cost of operation is 8 units, however, at the end of five years this cost may be 11 units, and the lease may be cancelled. Clearly, no "dominate" strategy exists for the institution since the results are the same irrespective of the choices made by the leasing entity. They may proceed to lease or build with equal confidence. The concept of operational gaming may be more appropriate for most building decision situations. The rules are less stringent, not requiring equal gains and losses. The method is generally to identify roles for each player and allow individuals to react accordingly with the assistence of specific mathematical models. The intent is to educate the players, i.e. to expose them to a simulated set of conditions which reflect the characteristics of their existing or potential real-life roles. Through repeated iterations, an appreciation is gained for the critical elements and impact of various decisions.

While each of the techniques discussed above responds to a unique set of circumstances, their potential application within the building planning and design process is considerable. Together they offer a clear and rational approach to building cost-benefit and economic analysis. It remains, then, to develop and extend this potential to a useable level, specifically directed toward those individuals responsible for plant planning, construction and operation.

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REVIEW OF SIMULATION MODELS AS AN ANALYTIC TOOL

Initially models were used exclusively for descriptive purposes, however, with the advent of new analytical tools, models could be used for predictive and explanatory purposes. "Today we employ symbolic models (mathematical and logical equations), iconic models (maps, globes and scale models), analog models (electric circuits, hydraulic and mechanical devices), and logical models (flow charts and computer programs)".[1] A model represents selected characteristics of a real or hypothetical system or situation. Simulation then is the use of a model to study a problem, without building the proposed system. Through simulation, experiements can be designed to reveal certain characteristics that will assess the interaction and ramifications of alternative decisions or policy and identify or resolve the critical issues in a system.

The variables for the model can be classed into two categories: deterministic or stochastic. The four common approaches to identifying these variables are through "introspection (by the builder or decision-maker), historical data, convenient approximations, and stated axioms".[2] In the technical areas related to the building process the significant elements are the stochastic events and processes which will account for the degree of uncertainty within the model. In the development of simulation models the builder should be aware of what uncertainties must be faced, how they influence the decision and whether the given model takes suitable account of the uncertainties.

As an analytic tool in the building process, the use of the computer based simulation models is still in the development phase. Many of the architectural simulation models that have been implemented fall into the category of waiting line or queueing models. In such cases people or equipment demand service from other people or equipment. By varying the distribution of demand and service times, a measure of the efficiency of the system can be obtained. Examples of this use of simulation are the Monte Carlo Simulation to Aid in Facility Planning at J. & L. Cleveland Works,[3] Simulating Cornary Care Units for a Defined Population,[4] and

Simulation Model for a Grain Sampling Facility.[5] Other areas where queueing models have been applied are for airport baggage handling and elevator simulations.

Simulation has also been used to forecast how a given configuration of heating, ventilating, and cooling systems will behave under given constraints or due to random events that will affect the model. Use of Computers for Environmental Engineering Related to Buildings[6] includes papers on the use of computers for both computations and simulations of energy, heating, ventilating and cooling requirements of buildings

The computer, with its capacity to store large quantities of cost and descriptive information and the ability to retrieve all or part of this data, has the potential to broaden the base on which decisions regarding facility planning and building development and operation are made. Depending on the nature of the data, the occurance of stochastic events could then be simulated to anticipate alternative future policies and configurations of the system. The level of decision making with such a simulation model is directly dependent on the inherent structural limitations of the model and on the quality and degree of specificity of the reference data base.

Included in the study at the University of Michigan on the Cardiac Care Unit (CCU) was the formulation, testing, and running of a computer based simulation model of the unit by the Architectural Research Laboratory. The objective of this model was to assist a planner in the determination of the number of beds in the CCU based on the number of cardiac cases generated in a service area, the admission and operation policy, the probability of not having a bed available on demand, and a rate for bed utilization. The data used in the model was collected over a 20 month period from 17 Michigan hospitals. The information on 2182 CCU admissions included age, sex, length of stay, type of complications and time of death if it occurred. Thus for a given sex and age distribution of length of stay and the probabilities of survival and the nature of the complications could be calculated. With this data a simulation model using the IBM General Purpose Simulation System (GPSS) was developed and tested for the computer. The GPSS model of the CCU based on the above data can, for a given number of cases per year, tell you what the likely bed utilization and what the probability of bed availability will be for a given unit capacity. Statistics on the number of cases and time they spent waiting can also be determined. With the use of the model, the planner can test the effect of different admission and discharge policies, of alternative unit configurations and of the impact of increasing the number of CCU cases. The preceding simulation is atypical of waiting line or queueing models that have been developed in facility planning where people or equipment are competing for service from a limited source. Based on a given data set and the probability for stochastic events to occur, a planner could develop a computer based model to simulate how the real system might operate over a convenient unit of time such as a week, month or year. Once the model has been built the results of alternative policies or plan configuration can literally be obatined in seconds. It must be emphasized that unless a clear definition of the problem and a statement of the objectives of the study are established, a simulation model may become so engrossed in simulating that more detail is extracted from the model than is needed or can be supported by the data available.[7]

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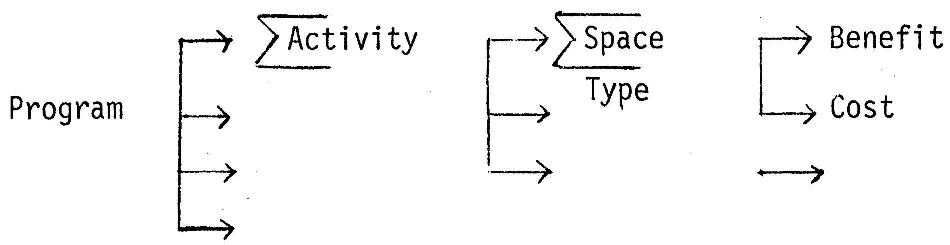
BUILDING BENEFIT: A LOGICAL STRUCTURE FOR APPLICATIONS

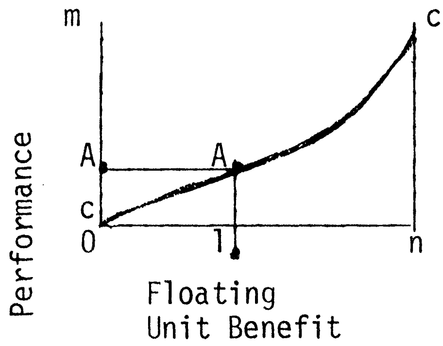
Three alternative methods for evaluating building cost are cost-benefit, cost-in-use and cost effectiveness. In the first case, both cost and utility are variables and each must be evaluated in a comparative analysis. Cost-in-use implies a choice of means to achieve a constant objective. In the third case, while the desired end remains fixed, the expeditious achievement of that end, as well as the cost, is considered for each alternative. Cost-benefit analysis are obviously preferable, however, they are also the most difficult to accomplish because utility measures are elusive and their relationship to cost is unclear.

Therefore, these two conditions must be resolved in order to proceed. For public institutions it is often advantageous to organize costs and benefits by programs and their respective intent. If programs are assumed to be composed of activities, and each activity can be associated with a building space type, then a link may be established between the abstract concept of program and the physical reality of plant facilities. Costs and benefits may be accumulated for space types and attributed to activities, and subsequently to programs. The general structure is as follows:



(1)

At this level the process is one of summation. Consider now the problem of assigning benefits, assuming for the moment costs can also be distributed, to each space type. If all aspects of each space are defined as characteristics, then their combined attributes represent the potential performance of the separate space types. Interpreting this potential through the activity requirements will yield a relevant measure of utility. Assuming that each characteristic will have an independent scalar measure or level of performance and benefit is evaluated on a sliding scale of 0-1.5 units, the following general relationship can be construted:



(2)

Unit Benefit Curve

For each characteristic, the curve, c-c, represents the perceived relationship, mathematical or intuitive, between performance and utility. The floating unit point, A, is the approximate desired level of performance achieved and B the corresponding derived benefit. Then:

$B = \gamma (P,A)$

where: γ = the function curve c-c

P = performance

B = benefit (3)

A = desired level of performance

Given this structure, the following conditions exist:

if: $P = A$, then: $B = 1$

if: $P < A$, then: $B < 1$

if: $P > A$, then: $B > 1$

Since the benefits are not cumulative, i.e., the absence of one characteristic may render a space useless, the combined utility measure is achieved through multiplication:

$B_{tj} = B_j * B_{jt1} * .....B_{jtk}$ For k characteristics where: (4)

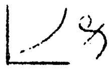
B_{tj} = total benefit associated with space typej, program t

Observe, that as P increases above the desired level, B increases proportionately.

Alternatively, as P sinks below the desired level, total benefits are lower. If P = 0 for one characteristic, there is no benefit derived from the space.

Three additional factors are required to incorporate the dynamic elements of benefit. They are maintenance lev , use level and rate of obsolescence. Diagram 1 is, thus, extended as follows:

.... $\sum$ Space Type → Characteristic



unit curve

(maintenance level, use level, obsolescence rate)

(M) (U) (O)

(5)

Where ς represents the adjustment overtime to curve c-c for factors M, U and O.

GEOGRAPHICAL SEGMENTATION OF MICHIGAN FOR LOCATIONAL BASIS FOR STATISTICAL COST FORECASTS

Given (1) If one wishes to use past costs of projects as a data base for forecasts of future projects and

(2) the last projects are in different locations within the State of Michigan then

Problem there is need to segment the State of Michigan so that (a) cost data from last projects in one locality can be compared to (b) cost data of past projects in another locality so that

in forecasting costs of future projects in one of these localities cost data from the other can be used as part of the data base for the forecast.

therefore

By what criteria can the State of Michigan be divided geographically to create such localities.

Alternatives Could be (a) Political Boundaries-counties, cities, etc., even SMSA

Really are artificial boundaries

(b) Physical Characteristics

(1) Land type

-too variable to group

-can be counteracted in the design, in the price of land

(2) Climate

-can be counteracted in the design of the building

-there develops a venacular style within adequate competitive work force

(3) Available daylight

-can be counteracted by change mix of resources, e.g., increase capitalisation, to meet prevailing conditions

(4) All of these have an influence on the price of a project-

-why the price is what it is in one location

-not how to segment an area (Michigan) into useable locations for statistical transfer of data

(5) These are physical factors influencing each location expressed in economic terms but which tend to be global to Michigan and counterable by a thinking designer.

(c) Economic

(1) Demand for construction (i.e., Market Place) i.e., Economic Base Areas

(2) Economic Base Area (economic catchment area)

-Fairly uniform level of price of basic construction resources

-Area of economic homogeneity evolving as one entity

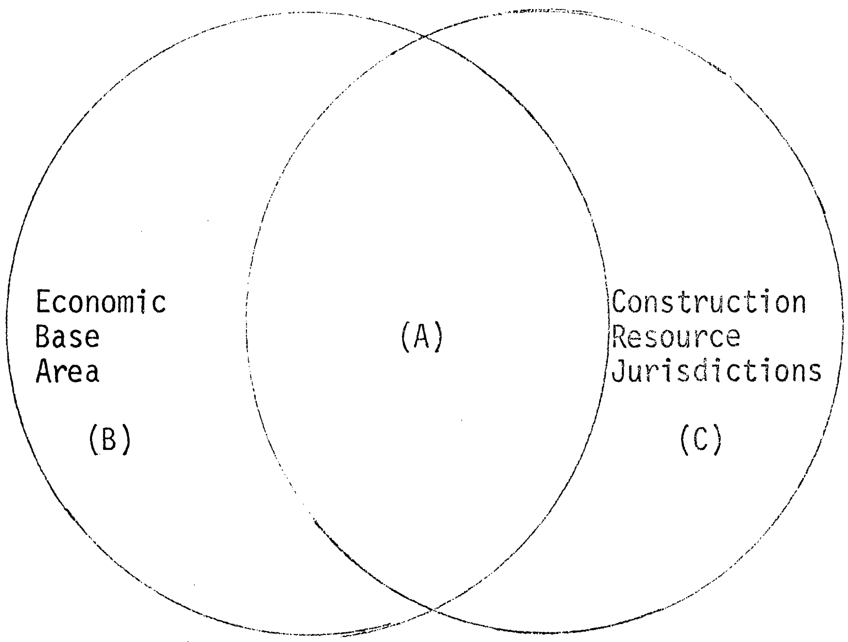
(3) Resource segmentation, i.e., building trades: unions, i.e., Building Trades Councils (locality group of union jurisdictions)

(4) Building Trades Council

-construction resource jurisdictional boundaries

-group of local unions forming one geographical area.

Conclusion



Area A Basic Area for Cost Indices Profiles, i.e., confluence of Economic Base Area and Construction Resource Jurisdiction

Area B Will be part of whole of another Area A

Area C It is unlikely that i will exist alone. If it does it should be considered as part of the Area A in which it is attached.

Within each Area A there should be defined its major type or types of buildings because within that area the prices of (a) typical buidings and (b) nontypical buildings may be different by the nontypical buildings carrying a premium. These major types of buildings should be in a set list of types of building for cross correlation across the State.

Footnote: Time - by year and by seasons of construction of each project should be another criterion used.

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