CONSTRUCTION MANAGEMENT:
Preliminary Cost Estimate and Scheduling of MIT's Civil and Environmental Engineering Building

By

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ABSTRACT

This thesis introduces the reader to the fundamental concepts of construction management, with emphasis on the cost estimation and scheduling aspects of this activity. The conceptual design of a new facility for the Civil and Environmental Engineering department, carried out by students in the Master of Engineering Program, is used as a case study.

Certain key considerations and problems that were faced are highlighted so as to broaden the understanding of the subject. The investigation represents an exercise in performing the essential tasks that constitute a preliminary budget and plan. The conclusions include observations and suggestions that need to be considered while attempting such a job in practice.

Thesis Supervisor: JEROME J. CONNOR, JR
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I am grateful to my parents, without whose love and encouragement I would not have had this opportunity.

Pushkar

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Objective and Approach

This thesis provides an introduction to the Principles of Construction Management with the focus primarily on the Scheduling and Cost Estimation aspects that govern the effective and timely delivery of projects. In order to further this understanding of the above mentioned, a case is studied.

The thesis starts of by giving a background to construction management and then moves on to define and broadly describe the following topics:

- Scheduling
- Cost Estimation

Next, the case to be studied is introduced. It relates to the preliminary design of a new Civil and Environmental engineering building at the Massachusetts Institute of Technology. This facility was designed by the Master of Engineering (High Performance Structures) group of 1999. A preliminary Schedule and Cost Estimate of the construction of the building is attempted here. Throughout the case, a conscious effort is made to apply and identify the implications of the several factors and effects that have been discussed in the previous sections of this document.

Scope

The thesis restricts itself to the broad classification of the constituent components of construction management as mentioned earlier, and only performs a preliminary investigation. However, this facilitates a clear though concise understanding of the critical role of estimation and scheduling on the construction of projects.

2 CONSTRUCTION MANAGEMENT

"The process of managing, allocating, and timing resources to achieve a specific goal in an efficient and expedient manner." [Reference 3]

Purpose and Importance

Construction Management is the method by which the project planning, design and construction phases of a project are treated as integrated tasks. The interaction between construction costs, environmental impact, quality and completion schedules are carefully examined so as to realize the project in the most economical time frame. Construction Management is essential to the success of all projects irrespective of size. A brief summary of the critical components of this activity are listed below:

- To work along with the owner and design team throughout the entire duration of the project while providing leadership to the construction process.
- To determine a target budget and time frame for the completion of the project.
- To monitor and maintain the project budget and schedule and quality requirements that have been established.
- To advise and coordinate procurement of materials, equipment and the work of all construction contractors. This would span the spectrum of payment to contractors, inspection to establish conformation with the design as well as look over changes and claims.

In recent times Construction Management has become an integral part of every project and is used widely throughout the world. A few key aspects in favor of its use are:

a) Savings in time result in less risk from variations in construction costs, and the earlier availability of the development.
b) A better control for the owner-developer in the progress of projects.
c) Use of Construction experts (CM) during the design as well as construction phases of the project.

d) Complete coordination over all activities associated with the project.

Essentials for Construction Management

The team involved in the construction management of the project, be it a corporation of its own or part of the general contractor, must ideally have some or all of the following skills and experience:

- Good oral and communication skills
- Knowledge of trades and trade contractors
- Knowledge of design and erection of structures
- Understanding of the architectural design
- Project Planning and Scheduling CPM/PERT
- Cost accounting experience for construction
- Experience in dealing with labor as well as judicial matters regarding disputes[4]

There are three assumptions that are made for the construction phase of the project.

Scope: The design plans and specifications contain no errors and meet the appropriate code as well as owner requirements.

Budget: The budget is acceptable to both the owner as well as the contractor in terms of the realization of the project.

Schedule: A schedule that is reasonable to the owner as well as the contractor.

Phases of Construction

The life cycle of a project leading to the product realization has six basic phases that contribute to developing in the project from an idea to reality.

Concept and feasibility studies: The construction activity begins with the identification of a need for a new facility. Long before any design work is undertaken and certainly well before field construction can commence, considerable thought needs to go into the overall planning. This constitutes the conceptual analysis as well as technical and feasibility studies.

Engineering and Design

These are usually the domain of architects and engineers and include preliminary and detailed engineering and design. The former stresses architectural concepts, economics, size and capacity decisions, and evaluation of alternative technological processes while the latter provides a detailed breakdown and analysis of each of the elements.

Procurement: As may be revealed from the name of this activity, this involves the obtaining of materials, equipment and the relevant contractors needed to execute the job as per specifications

Construction: This is the process where the designers' plans and specifications are converted into real physical structures. It involves the coordination of resources like labor, money, methods, and time, to name a few.

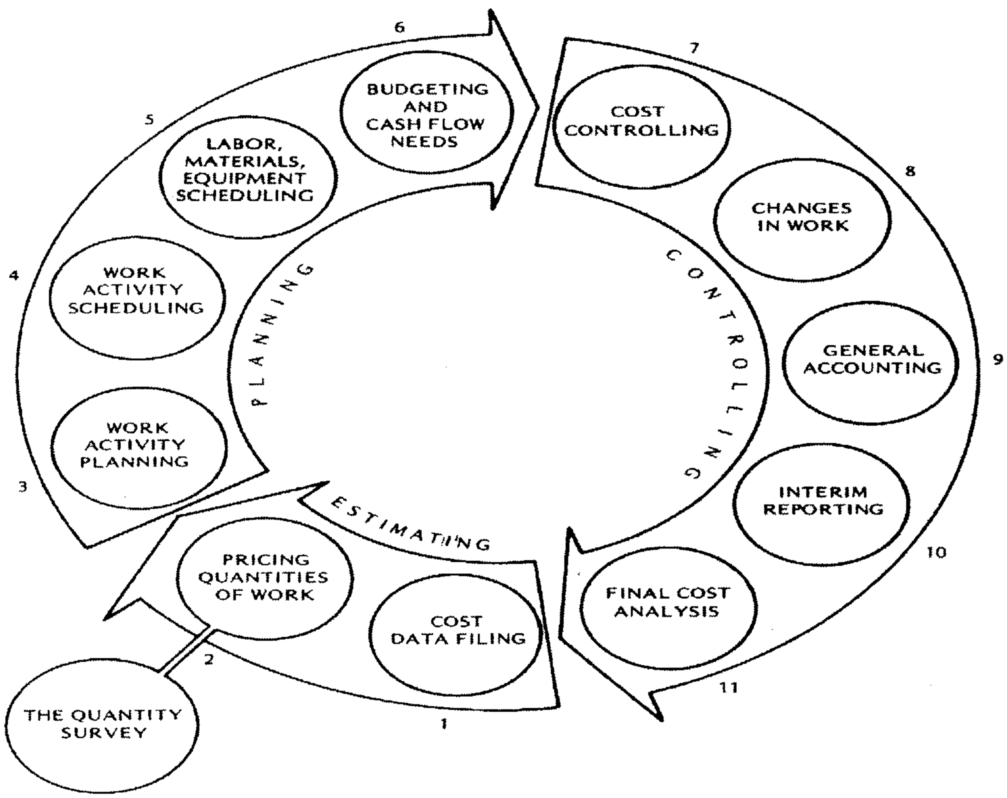
Start-up Implementation: Irrespective of the size or complexity of a project, much testing may be required so as to ensure that the components function well as a total system. Often, this is the warranty period within which the designer or contractor may be called back to correct problems that were not evident in the earlier stages of the project.

Operation ands Utilization: This phase essentially involves the maintenance and proper working of equipment and systems in the given project. The functional life of the project largely depends on the preceding phases of the project. In some cases, alternations may need to be made, in which case the first five phases of the project will be exercised.

The description of the phases that encompass a construction project right from the conceptual stage to the completion, reveals that cost estimation and scheduling are mandatory aspects critical to the success of all projects. These tools are applied throughout the entire process and at every stage. Let us take the conceptual phase as an example. An analysis of the economic feasibility as well as time required is necessary so as to decide whether the project is to receive the go-ahead. Similarly, during the design phase, a plan of the completion of the detailed design is required so that the construction phase of the project may be planned accordingly. Any disruption in the delivery of the different phases of the project may result in losses of both time and money. Hence, these two need to be given adequate importance throughout the development lifeline of a project.

The paper focuses on the application of the above mentioned to the construction process of the case study chosen earlier. Before we move into further detail it is important to fully understand the basic three phases of the estimation-planning-controlling cycle of construction management that is critical to construction phase. Figure 1[4] below shows a graphic representation of this cycle and is followed by description of each of the activities involved.

Figure 1: Estimation-planning-controlling cycle



Estimating

1. *Cost data filing*: an estimator draws on information obtained from other jobs in making an estimate
2. *Price quantities of work*: this completes an estimate and bid and may lead to a construction contract

Planning

3. *Work activity planning*: construction work is analyzed into parts which are then arranged in logical sequence
4. *Work activity scheduling*: estimated times for activities are included in a schedule for the project
5. *Labor, materials, and equipment scheduling*: amounts of resources required at different times throughout a project are estimated and scheduled
6. *Budgeting and Cash flow needs*: these are calculated and scheduled to find out the amount of financing required throughout the project

Controlling

7. *Cost Controlling:* daily costs of major items are obtained and compared with the amount of work performed; resultant unit rates are compared to those in the estimate; unsatisfactory production rates are discovered and corrections in work methods may be made.
8. *Changes in work:* these require costs to be negotiated and recorded
9. *General accounting:* including payrolls and payment for materials and equipment rentals, and for cost of accounting requirements
10. *Interim reporting:* on actual costs and progress periodically made the schedule adjusted accordingly
11. *Final cost analysis:* compares actual costs and times spent on work activities with those in the estimate and schedule to provide information for future projects.

Having seen the construction cycle that most projects follow, the two most important tools used in the construction process, are cost estimation and scheduling. They are discussed in further depth in the next two sections to follow.

3 SCHEDULING

Principles

The key to a successful project is good planning. Planning provides the basis for the initiation, implementation and termination of a project. It sets guidelines for specific project objectives and milestones. This activity involves the overall planning, scheduling, and control needed to sequence operations properly and allocate resources effectively. Therefore, it would not be incorrect to claim that scheduling is one of the most essential components of the design and construction phases of a project. The theme that underlines this process has been illustrated in a simplistic form in the figure below.

Figure 2: Theme that underlines Scheduling

Set Goals → Plan

Scheduling is a fundamental and challenging part associated with the management and execution of construction projects. This is critical in the establishment of the four desired results, as follows: First, the completion of the project on time with a smooth and uninterrupted flow of work; second, to increase communication between all parties that are involved in the project so as to reduce rework and minimize confusion and misunderstandings; third, accountability of peoples' responsibilities/authority as well as a clear understanding of individual and group tasks; and fourth, the integration of all work to ensure a quality project for the client.

In order to accomplish this, the project must be broken down into well-defined work tasks (sub projects). The detail as well as relationship between these individual tasks must be determined. It often uses various computer software programs and systems to formulate clear outlines for the several complicated tasks involved and interactions among these different tasks. The requisites of such schedule are listed below:

- A plan of work activities (Work Breakdown Schedule)
- A calendar showing dates and duration of the tasks
- A graphic representation of the schedule as a bar chart or logic diagram
- Monitoring and Control of activity times
- Reporting and recording activity times so as to compare with the baseline schedule
- Modification of work if required

Before we move on, it is important to run through certain activities that are essential to a complete understanding of the scheduling process. Planning must begin before the start of a project rather that after. It must include knowledgeable people who are to consider all aspects of the project namely, scope, budget and quality. A plan must build with considerable flexibility so as to include allowances for changes and time for reviews and approvals. Therefore, a schedule is a plan for doing work and will never be followed precisely. Finally, the plan must be simple so that it may be easily and effectively communicated to all parties involved.

There are various techniques used for scheduling a project depending upon its size, complexity, personnel and owner requirements. There are two general methods that are commonly used: the Gannt or bar Chart and the Critical Path Method.

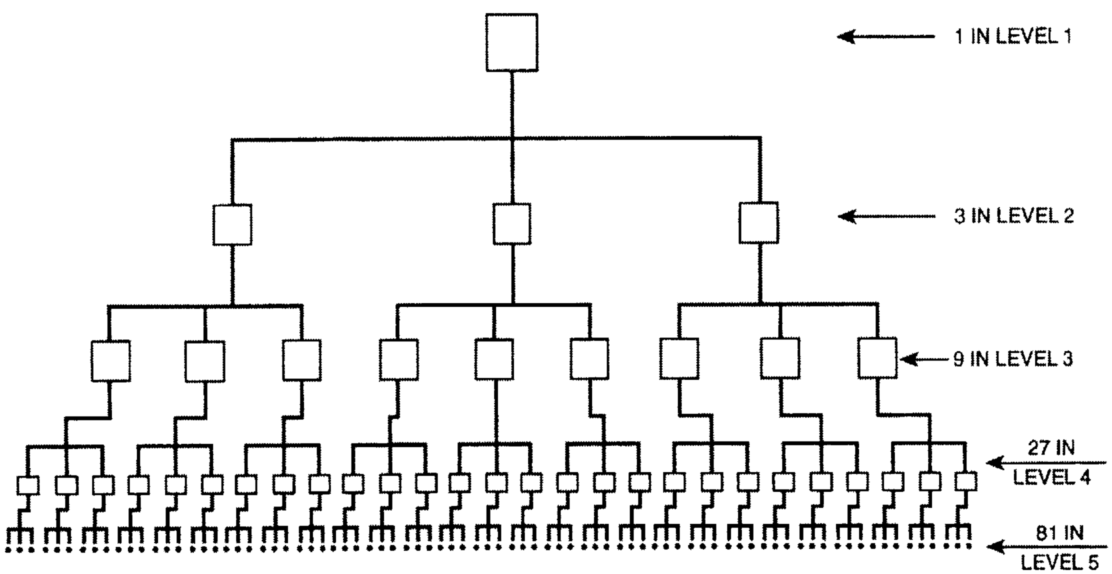
The bar chart, developed by Henry L. Gantt, is a graphical time-scale representation of the schedule. It is relatively easy to interpret but may be difficult to update and does not show interdependencies of activities. Another disadvantage of this method is that it does not integrate costs or resources with the schedule. Though this method is effective in the overall project scheduling, its applications are limited for detailed construction work.

The Critical Path Method (CPM) was developed by DuPont Company as a deterministic approach to scheduling. Today, the CPM method is commonly used in the engineering and construction industry. The CPM provides interrelationship of activities and scheduling costs and resources. It is very effective technique overall project scheduling as well as detailed construction scheduling. However, it does have some limitations concerned with detail construction scheduling since extensive information may be required early on in the project. Although the CPM technique requires more effort than a Bar Chart it provides information essential for effective construction management. A similar method called PERT was developed by the US Navy, which provides a probabilistic approach.

Work Breakdown Structures

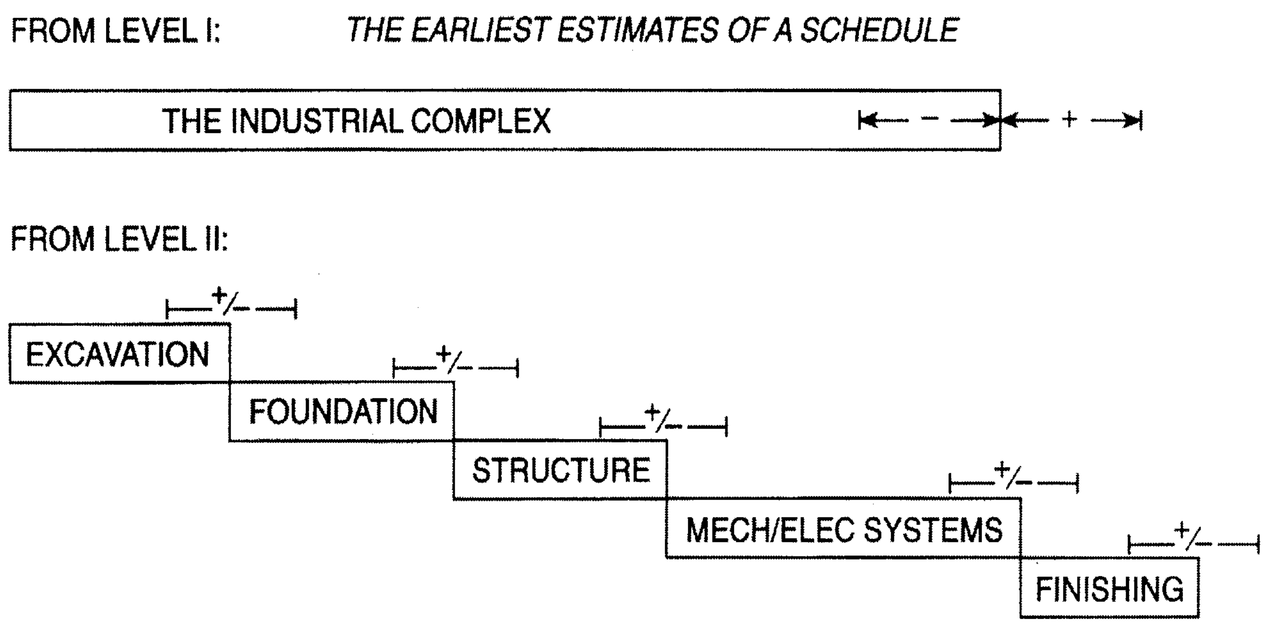
A work breakdown structure (WBS) is the first step toward constructing a schedule. One begins by specifying a goal statement for the project and then successively subdividing that goal into smaller and smaller portions until all the basic construction objectives have been identified. The WBS forces the planner to compartmentalize his thinking as he goes deeper into the series of objectives to be performed. Once the identified tasks have been detailed in a manner that facilitates completion by a specific crew then further subdivision is not necessary. Figure 3[5] below illustrates the levels to which detailing may be done when required.

Figure 3: Hierarchical decomposition



Schedules may be formed using these work breakdown structures and the series of forecasts that result have been shown in figure 4[5] below. It may be important to note that only a detail down to level 2 has been shown.

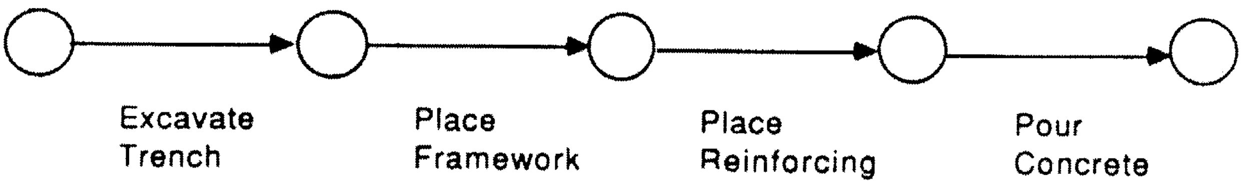
Figure 4: A sample 2-level detail schedule



Concepts of Network and Precedence

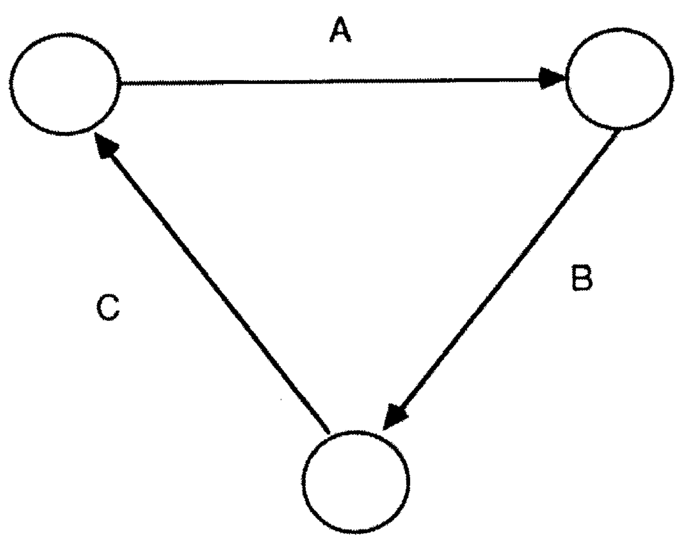
The essential elements in almost all project networks are *activities*, their *durations* and the *logical interrelationships* among them. Once these have been defined, the *precedence* relations would signify the order in which they would be completed. There are certain sequences that are required so as to ensure structural integrity and regulations. Most precedence relationships are very complicated and include not only multiple activities but also *lags* between activities. Figure 5[1] below shows a diagrammatic representation of a simple activity sequence. The arrows form the links between the nodes or events.

Figure 5: Example of a precedence diagram



Certain errors that should not be made while forming a precedence relationship are shown in the figure 6[1] below. A circle of such activities will ensure that a project will never start and therefore never finish.

Figure 6: Errors that must be avoided during precedence networking



Critical Path Method

Given the precedence relationships, we can compute each activity's early start, late start, late start, late finish, total float and free float. Float is a measure of the flexibility available for re-scheduling a task or a chain of tasks.

These computations will yield the total expected duration of the project and focus attention upon the most *critical activities* and the **critical path** for the project. The Critical path may be defined as the path through tasks that has zero total float. This concept is central to an appreciation of scheduling because that duration of the project is sensitive to the duration of each critical task.

The critical path should always be identified on a network diagram since it governs the timely delivery of the project. This is a powerful concept and an essential tool in the management of projects.

The figure 7[5] below shows a typical network diagram for a single activity and some of its important components.

TASK NO.	DUR.	TF	FF
TITLE OF TASK			
EST		EFT	
LST		LFT	

ES - Early Start

EF - Early Finish

EF - Late Start

LF – Late Finish

Figure 7: Typical Network diagram

Delays and Constraints

Most schedules are initially formed as simple ideal case scenarios and then developed into realistic ones by incorporating complexities that are likely to occur. A time cushion is often included to account for some factors that may be a source of potential delays. Below is a list of some factors and situations that are usually taken into consideration.

- Contingency allowance for time slippage
- Weather Delays (using statistical data as well as forecasts)
- Other predicted or unexpected concerns – religious holidays, labor strikes, etc

In the case study that is to follow later, the use and implications of these factors will be demonstrated.

4 COST ESTIMATION

Purpose and Importance

The purpose of estimating is to determine the forecast costs required to complete a project in accordance with the contract plans and specifications. The estimator can produce, within reasonable accuracy, the total costs for a given project. There are two distinct tasks in estimating: to determine the probable real cost and to determine the probable real time to build the project. This aspect mentioned above is of significant importance and allows an integration of the estimating and scheduling functions of construction management.

The process of estimation serves three main functions in the construction industry:

1 An estimate of the probably cost of construction is required in the early stages of a building program in order to determine whether or not a project is financially feasible. This estimate is produced from a minimum detail since no detail designs are available and the project is still in infancy.

2 Estimates are required in cost control programs to facilitate the control of the expenditure of funds on a project. Cost management during the design phases of a project include considerations of alternative designs that help direct the decision making process better. Also, once construction is underway, this estimate provides a benchmark for the contractor to identify deficiencies and take corrective actions so as to maintain profit margins.

3 This results in the competitive bidding process by which most construction contracts are awarded. Providing a good forecast is central to the contractor winning a bid.[6]

Types and Methods of Estimates

It is important to define the scope of a project so as to identify items and activities that are required to meets the needs of the owner. This definition will provide sufficient information to list the work to be performed so that neither the project budget nor the schedule is adversely affected. The Table below provides a brief checklist for a typical building project.

1. General

Size of building, design for minimal investment, layout and provisions for expansion, parties involved, expected life

2. Site Information

Access to site, access to utilities (water, electricity), climatic conditions, soils conditions, acquisition of land, and space available for construction.

3. Buildings

Number, type, occupancy, intended use, quality of finish, landscaping and parking requirements.

4. Regulatory Requirements

Permits, regulations, safety, and environmental issues.

There are numerous methods and levels of accuracy for preparing capital cost estimates for a construction project. Each method has its appropriate applications and limitations, but it is important to recognize and emphasize that all estimates are approximations based upon judgement and experience.

The methods of estimating may be divided into three categories:

- conceptual and preliminary estimate
- detailed estimate
- definitive estimate

Conceptual and preliminary estimates: As the name suggests, are generally made during the initial stages of a project. It essentially helps reveal whether a project is economically feasible. Once a decision has been made then the estimates may be refined as we go further into the detailed design phases. Though these estimating procedures vary considerably, most of them will fall into one or more of the following categories.

1. Time-referenced cost indices - These show cost changes over time. They may also reflect changes in technology, methods, and productivity as well as inflation trends. This type of estimate is usually applied to the construction phases of the project.

2. Cost-capacity factors - While Cost indices focus on cost changes over time, cost capacity factors apply to changes in size, scope and capacity of projects.
3. Component ratios - As the engineering and design progress, more information may be obtained about the project and its elements. This helps determine the size and types of the major equipment that are needed and puts the construction management personnel in a position of solicit price quotations.
4. Parameter Costs – This approach relates all costs of a project to a few physical measures or 'parameters' that reflect the size and scope of that project. A simple example of this may be the 'gross area enclosed' in which all cost like labor, foundations, structural steel, roofing etc would be included.

Detailed Estimates: Once the conceptual design has been approved and most of the design work completed, approximate estimates are generally supplemented by detailed estimates. These will usually include a careful tabulation of the quantities for a project; this is called a "quantity takeoff". These quantities are then multiplied by selected or developed unit cost which results in the direct costs for the facility. The two types of detailed estimates are the fair cost estimates and the contractor's-bid estimate in order of level of detail. These will not be explored further, but it may be important to note that proper evaluation of the effects of local practice, weather conditions, market competitiveness as well as the completeness of plans and specifications is extremely critical for the accuracy of such detailed estimates.

Definitive Estimates: As the project evolves, initial approximate estimates are refined and accuracy is brought about by bringing in additional information. At a certain point in the process a definitive estimate can be prepared that will forecast the final project cost with little margin for error. Projects may be classified into four different categories for purposes of definitive estimates:

1. Unit-price projects: These usually encompass heavy construction jobs such as dams, tunnels, highways and airports. Here the price is set constant while quantities may vary within limits inherent in the nature of the work.
2. Traditional: Projects in this category include lump sum, guaranteed maximum-price, and cost-plus-a-fee negotiated contracts.

3. Design-construct: These are similar to the traditional type of projects mentioned above.

4.3 Measurement of Quantities

An estimate begins with a quantity take-off. A quantity take-off is the process of measuring the work of the project in the form of a series of quantified work items. In order to prepare this the estimator has to break down the design that is shown on the drawings and described in the specifications. It is common to maintain a catalog of standard items that are usually encountered in large-scale construction though it is not unusual to come across new categories of work unique to the project undertaken.

Measurement: The estimator measures the take-off quantities and not quantities of materials. The difference between work quantities and material quantities is a subtle one and important to understand. The differentiation between a materials take-off and a cost take-off have been listed below:

1. Measurements are made in 'net in place' with cost estimates while materials take-off measure gross quantities.
2. Material take-off often does not provide enough information for pricing.
3. Cost estimates have a number of items that do not have involve material and may only include labor prices.[6]

Before we go further into the subject it may be helpful to realize what "add-on" components are and the reason they are widely used in the estimation process. As mentioned earlier, estimation provides an educated expectation of the costs of a project and must include finer adjustments. This is brought about by the use of waste factors, swell factors, compaction factors and other adjustments to name a few.

The theme underlined in above has been illustrated in a simplistic form below:

Final Estimate = Net in place quantities + Add-on's

It is extremely important to understand the reasons behind take-off 'net in place' quantities for cost estimation. Some of the reasons that support this are:

1. Consistency – To avoid difficulties that may arise from some estimations being in 'gross' quantities while others as 'net' quantities. This will help in the assessment of different estimates and result meaningful comparisons. Also, a standard data base may be maintained

2. for "add-on" by a set of estimators (from the same company) so as to ensure effective communications and no barrier.
3. Objectivity – Measuring 'net' quantities is a rather arbitrary decision and may cause different amounts of quantities to be produced by different estimators. Such disagreements are easier to remedy if the unit prices are compared and when the quantities have been measured in an objective and standard fashion.
4. Unit Price Contracts – Such contract measurements require the work done to be measured as 'net' quantities so that it does not give scope to claims in variations of work done i.e. due to different wastage factors added by contractors to increase quantities.
5. Comparisons of Operation Efficiencies – The efficiency of construction projects must be measured on an objective rather than subjective basis. If this is not done, such a analysis will be meaningless and futile.

5 CASE: Civil and Environmental Engineering Building (MIT)

5.1 The Project

The Master of Engineering group of 1999, of the department of Civil and Environmental Engineering, had undertaken the hypothetical conceptual design of the Civil & Environmental Engineering Department building at MIT. This highly innovative building complex was an exercise in product realization and is used as an example in this thesis. Once the project is described, a preliminary cost estimate and works schedule for the construction of the building will be presented.

Site Description

MIT is presently developing the northeast section of its campus with the recent completion of the Biology building and Media Laboratory. The Proposed Civil and Environmental Engineering building is also to be located in the northeast section of campus. Directly south across Vassar Street will be the new Electrical Engineering and Computer Science (EECS) building, currently being designed by renowned architect Frank Gehry. Together, these two buildings will form the new gateway to the MIT campus.

Figure 8: Proposed site layout[13]

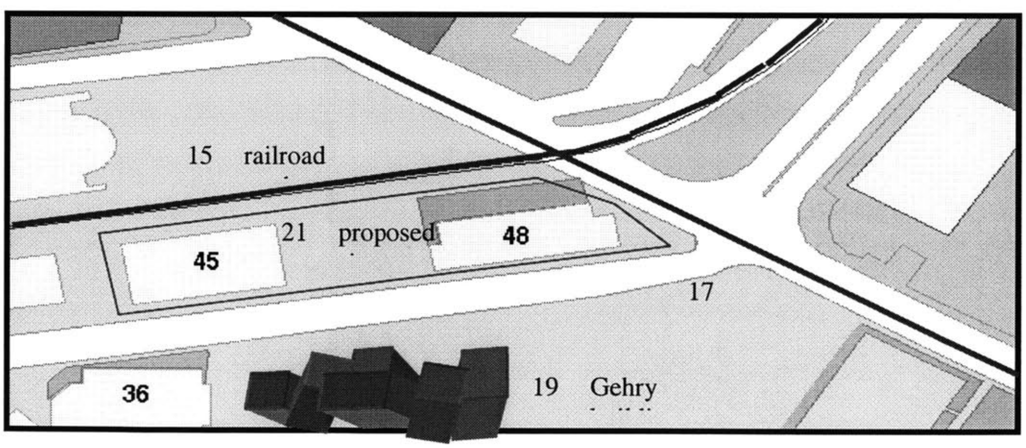


Figure 8 gives a view of the proposed building site with its surroundings. The site is long and narrow, constrained by the railroad tracks on the North side, Vassar Street on the South, and Main Street on the East side. The MBTA Red Line runs beneath Main Street, and the proposed Purple Line will run beneath Vassar Street.

The proposed site covers MIT Buildings 45 and 48. Building 45 is the Animal Care Facility, a Division of Comparative Medicine, and Building 48 is the current Environmental Engineering building. The dimensions of the available space are approximately 700 feet by 90 feet, and the building-height is restricted to 120 feet by the Cambridge building code.

The Building

Once the concept that was developed in greater detail in the Master of Engineering project was th "Cascade Building", a five-story building of step form and rectangular plan area. Its roof system is an arrangement of elliptical paraboloids, triangular in plan. A basement is also provided throughout the entire footprint of the building. Figure 9 below shows the final result. It is a building that is flexible, aesthetically pleasing, structurally exciting, and energy efficient.

Figure 9: The building[13]

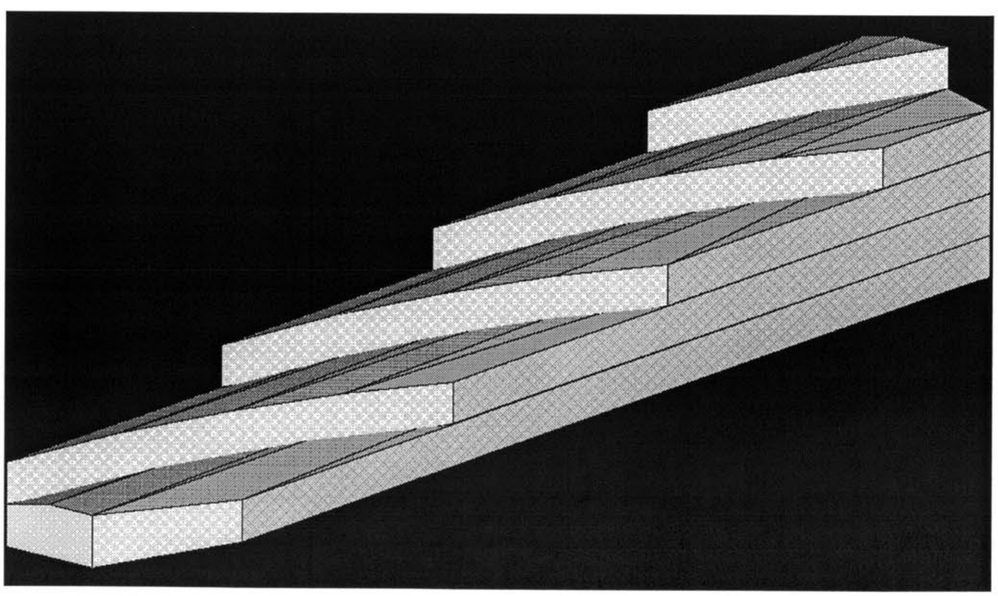


Figure 10: A look at the Cascading shells[13]

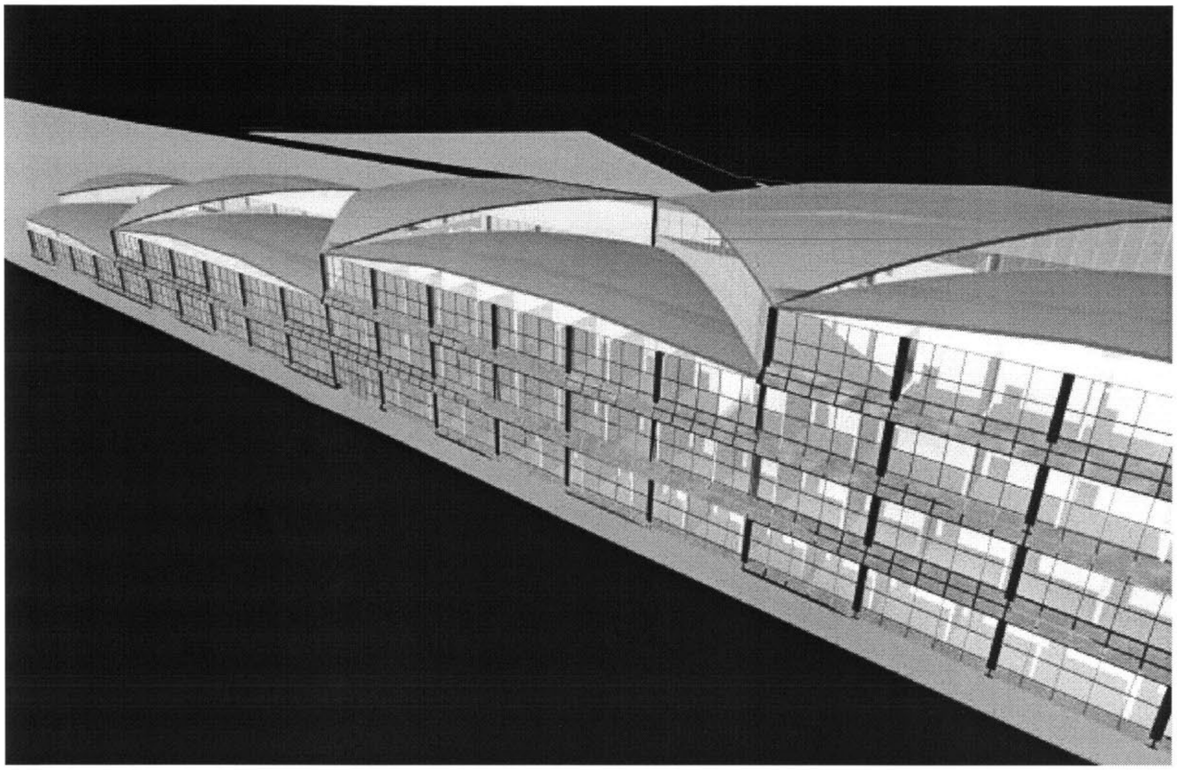


Figure 10 above provides a rendered elevation of the completed conceptualized design model of the Civil and Environmental Engineering building.

The structure:

A wire frame representation of the 'Cascade' building can be seen in Figure 11 below. It consists of an entirely steel framework with five key features:

- Trusses spanning the 75-ft width of the building

- Beams and Columns of 'I' cross-section, pin connected
- No internal columns
- Cast in place concrete floors
- Bracing systems along the elevator/stair cores

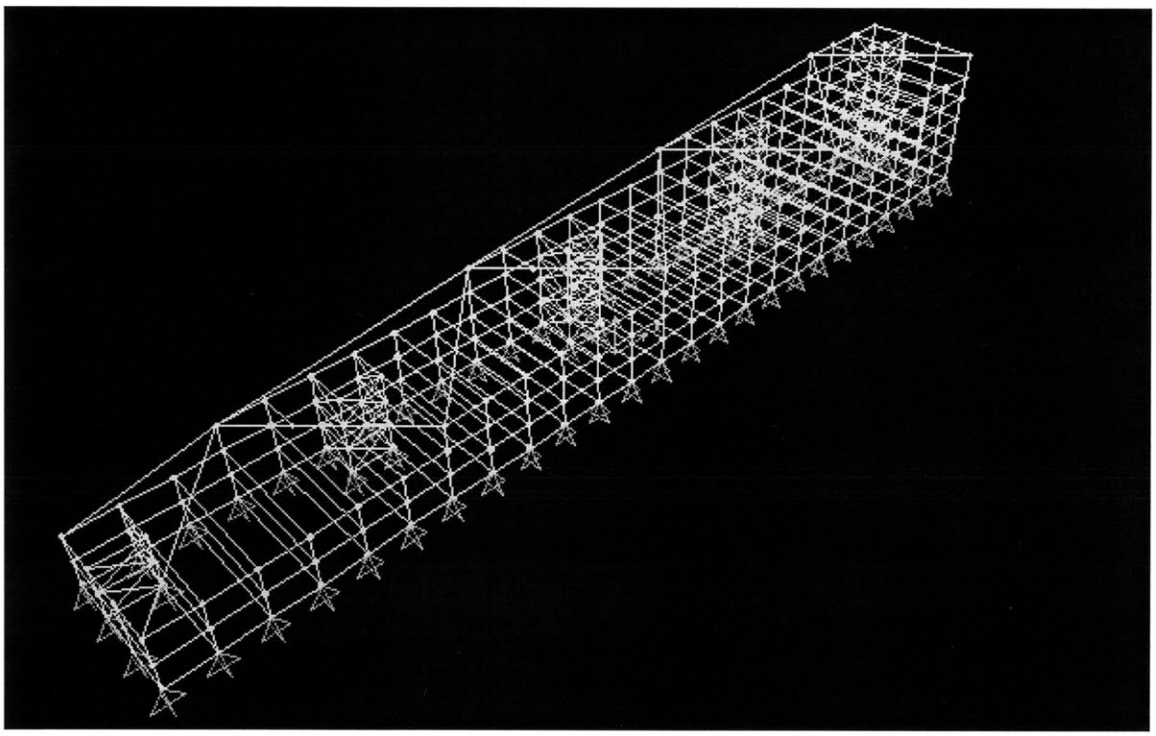
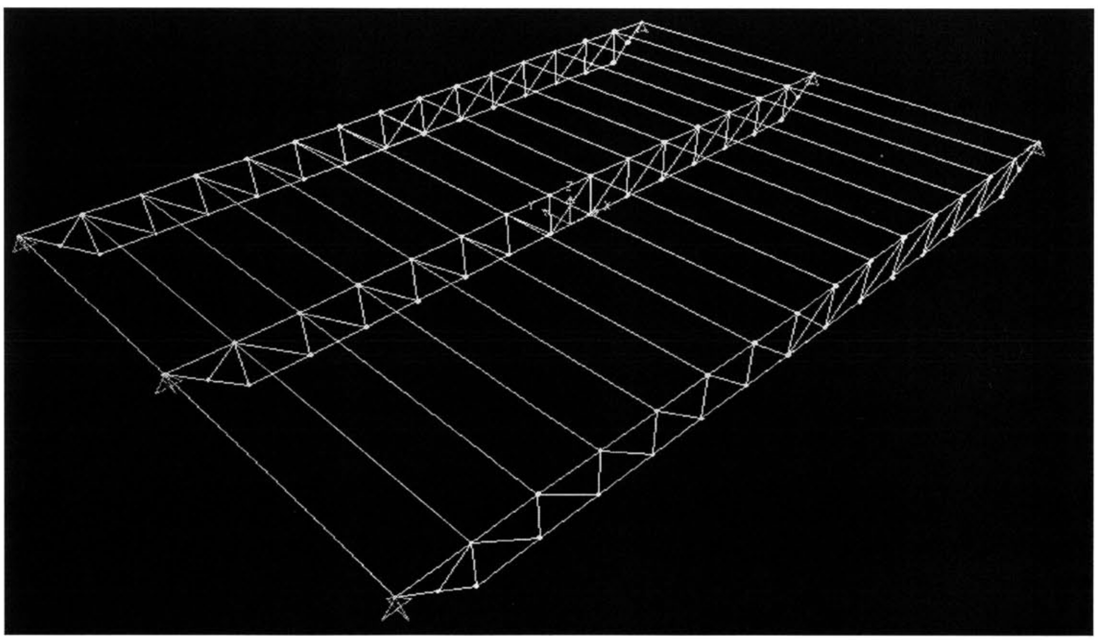


Figure 11: A wire-frame representation of the building[13]

Figure 12 below gives a closer look at the floor system. Briefly, this consists of:

- Trusses spanning the 75Ft width of the building along the entire length of the building
- Beams at 5Ft connecting these trusses
- A four inch thick cast in place concrete floor slab

Figure 12: A detailed look at the floor system[13]



Besides the above mentioned, the building has also been base isolated to survive earthquakes. The concept of isolating the superstructure from the substructure has always been an elegant idea in theory but only recently has become a viable solution. The goal is to have a flexible material in the horizontal plane that is capable of dissipating energy flow into the superstructure. Figure 13 below shows a typical base isolator that may be placed under the columns of the building.

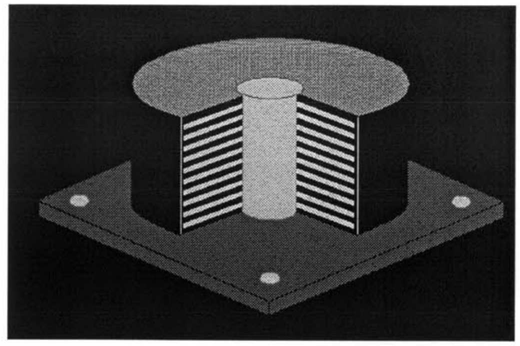
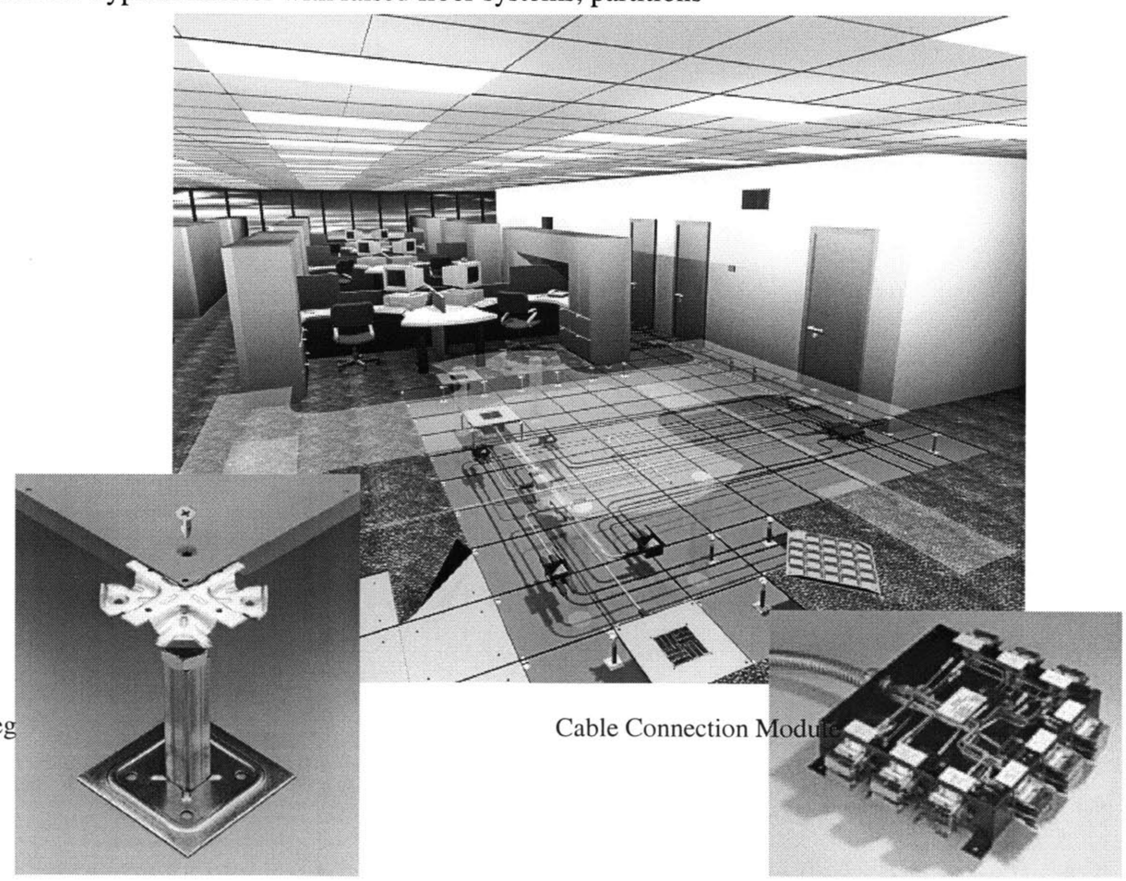


Figure 13: A typical base Isolator[13]

As mentioned earlier, the building was designed to be a statement of Civil Engineering and hence includes several high performance features. This means the use of intelligent systems throughout the building like, raised floor systems, photovoltaics and glass claddings, flexible partitions, etc to name a few.

It is beyond the scope of this thesis to describe in detail as to how these systems function. However, to assist in the understanding of their location in the building, figure 14 has been shown below.

Figure 14: Typical interior with raised floor systems, partitions[13]



Typical Floor Leg

Cable Connection Module

Figure 15: Overview of the 'Cascade'[13]

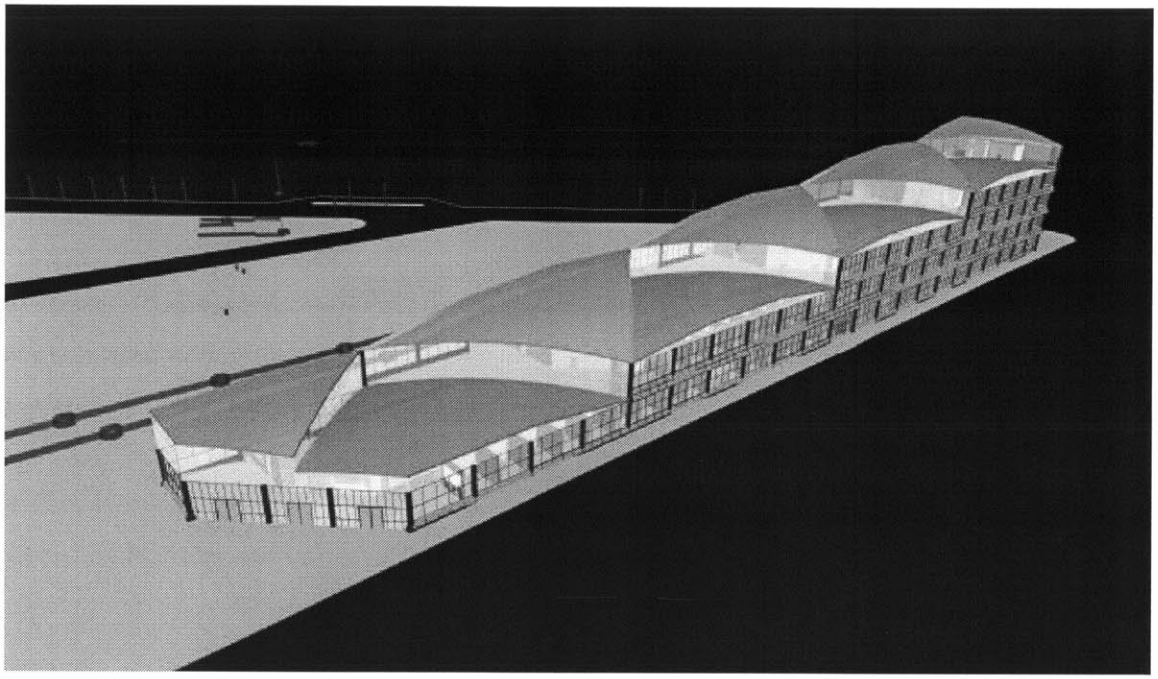


Figure 15 provides an isometric view of the entire Civil and Environmental Engineering facility on the proposed site.

Quantity Survey and Cost Estimate

The proposed 'Cascade' building will require an accurate measurement of all quantities that are necessary for the construction process. A break down of the important components and relevant comments will follow. Appendix A contains all the relevant drawings and essentials relating to the task proposed above.

In order to attain the information necessary to perform a cost estimate, appropriate details of the design were obtained from the structural as well as geotechnical engineering teams. This was an outcome of effective communications and coordination. The discussions that resulted cleared all the ambiguities that surfaced and were followed up by further consulting sessions whenever required.

Demolition

The cost of demolition of building 48 and 45 have not been calculated since a real estimate has been obtained from reliable sources in the facilities administration office at MIT. The cost of the above mentioned stand at $800,000.

Excavation and Foundations

The site to be excavated has a cross sectional area of 810ft x 85ft and a total depth of 32ft. The foundation system consists of 3ft thick slurry walls running along the perimeter of the building and going to a depth of 50ft. The concrete slab on grade will be 8ft thick and span the entire base of the building. It is proposed that the construction of this section of the building will follow the following procedure.

1. Put slurry walls in place
2. Excavate and remove existing base slab
3. Continue excavation (to a depth of 32ft)
4. Place struts to hold soil walls
5. Pour slab on grade (8ft thick)

It may be noted that the demolition of the superstructure has already taken place.

An important consideration that is often overlooked but may result in delays and problems in the future is the swell factor of the excavated material. The excavated soil tends to swell or increase in volume after being removed because it no longer under loading. Different swell factors apply to each of the soil types of soils.

The Table below shows the soil profile and respective properties soil types that we will encounter during excavation. It may be noted that relevant geotechnical extracts from the Master of Engineering Project report may be found in Appendix A.

Table 1: Soil profile with swell factors[13]

Type	**Swell factor (%)**	**Depth (Ft)**
Fill	25	0-12
Silty Peat	20	12-20
Sand/Gravel	15	20-28
Upper Boston Blue Clay	35	28-100

Detailed calculations that were conducted in order to obtain the cost estimates presented may be found in Appendix B. These have incorporated swell factors as well as other considerations.

The table 2 below presents the summarized cost estimates.

Table 2: Summary of Cost Estimates for Excavation and Foundation phase[10], [13], [15]

Activity	Cost ($)
Placing of Slurry Walls	5,316,750
Excavation and Disposing of Soil	1,242,095
Placing the Base Slab	5,358,450
Total	11,917,295

Superstructure

Earlier sections described the structure at a macro level without going into details of member sizes. These sizes are critical to the survey to be conducted for this part of the estimation and have been appended for reference. The procedure to be adopted in performing this estimate is based on advice obtained from a well-known steel fabricator and erector working on the East Coast, Helmark Steel Inc[14]. It is proposed that the total mass of steel be calculated and trebled to obtain the total cost of the final product. Though this seems trivial it is known to be surprisingly accurate, especially for our purposes. The tables 3 & 4 below show the total required mass of steel as well as the related costs.

Table 3: Superstructure components and respective mass

Item	Mass (Tons)
Coulmns	9.4
Trusses	1,620
Bracing	14.3
Beams	33.1

Table 4: Total Mass and Cost of superstructure

Total Mass (Ton)	Total Cost ($)
1,677	1,509,464

* Effective rate of $900 per ton

As far as the 4-inch thick cast in place concrete slab is concerned, the Means Cost data was used to work out the respective costs. The roof structure construction of this building is predicted to be a rather difficult one considering the peculiar nature of the shape of the concrete shell membranes. Consequently, a summary of these costs along with those of the photovoltaic cladding system, which is also expected to be equally important, have been given below.

Table 5: Other items like floor system, roof and photovoltaics

Item	Cost ($)
Floor System	1,285,671
Roof	1,125,000
Photovoltaic Cladding	3,840,000

The base isolation system requires the purchase and installation of 60 base isolators, each of average cost $1000. Since this procedure is relatively new additional margins have been added in the estimate to incorporate ambiguity.

Interior Construction including HVAC

The innovative approach of the design demands the adoption of a raised floor system that will include all the functions of a typical HVAC system as well as encompass electrical and other service distribution needs of the facility. The cost estimate the section of the building have been obtained from Tate Floor Systems Inc.[16] a leading manufacturer, installer and promoter of this system for the last 20 years. Table 6 below provides the results obtained. This table also includes other essentials that are required for the project namely, elevators, finishes, etc.

Table 6: Rate and Cost for Interior systems

Item	Rate ($)	Total Cost
Tate Raised Floor System[16]	29.07 per sf	4,578,525
Elevators	40,000 (each)	120,000
Floor Finishes	11.7 per sf	1,847,750

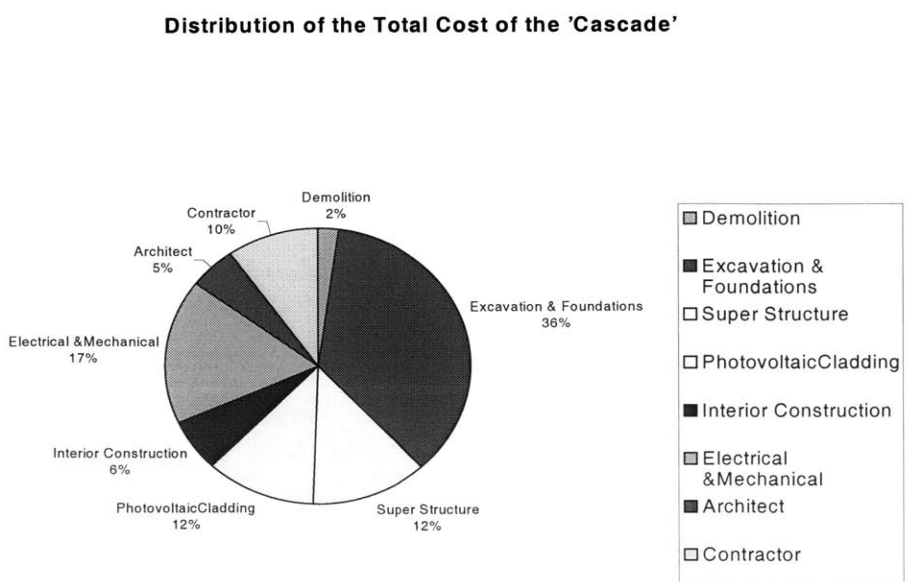
Site and clean up and Miscellaneous

The cost for the site set up and disassembling activity, though small compared to the overall cost of the project has been embedded into the computations done earlier. As far as the contractor and architect are concerned, it has been assumed that the will have margins of 10% and 5% respectively.

The Overall Cost

The figure 16 below displays the total anticipated cost of $36,662,672 of the entire facility and highlights key components. It demonstrates the important constituents and identifies major areas of concern.

Figure 16: Chart of overall cost breakdown of 'Cascade'



Scheduling

This section explains the development of a preliminary schedule based on selected tasks that are seen to be critical to the realization of this project. With reference to the previous section on scheduling, identification of activities of a certain degree of detail was be conducted following which precedence tables were be developed. Subsequently, the duration of the respective tasks will be determined and a schedule computed using Primavera. Today this software is commonly used in industry and forms a vital part of the construction process due to certain functions, namely,

- Features to compare actual progress to planned
- Simple methods to update work in progress
- User friendliness
- Provisions for delay

The activities to be performed and their key precedence logic are shown in the table below.

Table 7: Activities to be performed and their precedence logic

Activity	**Precedor**	**Successor**
Site Services	None	Demolition
Demolition	Site Services	Excavation
Slurry Walls	Demolition	Excavation
Excavation	Demolition	Basement Slab
Basement Slab	Excavation	Place Isolators
Place Isolators	Basement Slab	Erect Steel
Erect Steel	Place Isolators	Roof
Concrete Slabs	After certain progress in Steel Erection	Elevators
Elevators	Concrete Slabs	Site Clean Up
Roof	Erect Steel	Insolation
Stairs/Ex Doors	Concrete Slabs	Finishes, Cladding
HVAC	Erect Steel	Finishes
Cladding	Elevators, Stairs/ Doors	Site Clean Up
Finishes	Stairs/Ex Doors	Interior Partitions

Interior Partitions	Finishes	Site Clean Up
Site Clean Up	Roof, HVAC, Cladding, Interior Partitions	Grace Period
Grace Period	Site Clean Up	None

Table 8 below shows the duration for the respective tasks. Details of their origin may be found in the appendix C.

Table 8: Duration of the tasks to be completed [10, 11, 12, 15]

Activity	**Duration (Days)**
Site Services	6
Demolition	10
Slurry Walls	70
Excavation	30
Basement Slab	9
Place Isolators	1
Erect Steel	90
Concrete Slabs	70
Elevators	15
Roof	45
Insolation	5
Stairs/Ex Doors	20
HVAC	40
Cladding	17
Finishes	60
Interior Partitions	60
Site Clean Up	7
Grace Period	50

The utmost importance is given to ensuring project delivery in the shortest time feasible keeping in mind that this may have an impact on the cost estimation performed earlier. The main principles that guide this approach are compliance with the precedence logic established earlier and identification of the critical path. Allowances must be made for unpredictable delays that may surface and result in the postponement of work.

The figure 17 on the following page is a Gantt Style representation of the construction process. This analysis has resulted in a completion date for the project to be 24th January 01, assuming a start of 31st March 1999.

In figure 18, a PERT system display follows. The critical path may be seen marked in red. In accordance to with what had been mentioned in earlier chapters, there is no float allowed on this path. All activities on this path are essential to the timely completion of the project. It may be noted that due to the uncertainty inherent in an analysis of this type and at such a stage, grace period for completion of the construction has been added to account of delays and constraints that are not yet apparent. Such grace period are not common practice in real construction and have been included only due to certain problems faced that could not be translated in time required.

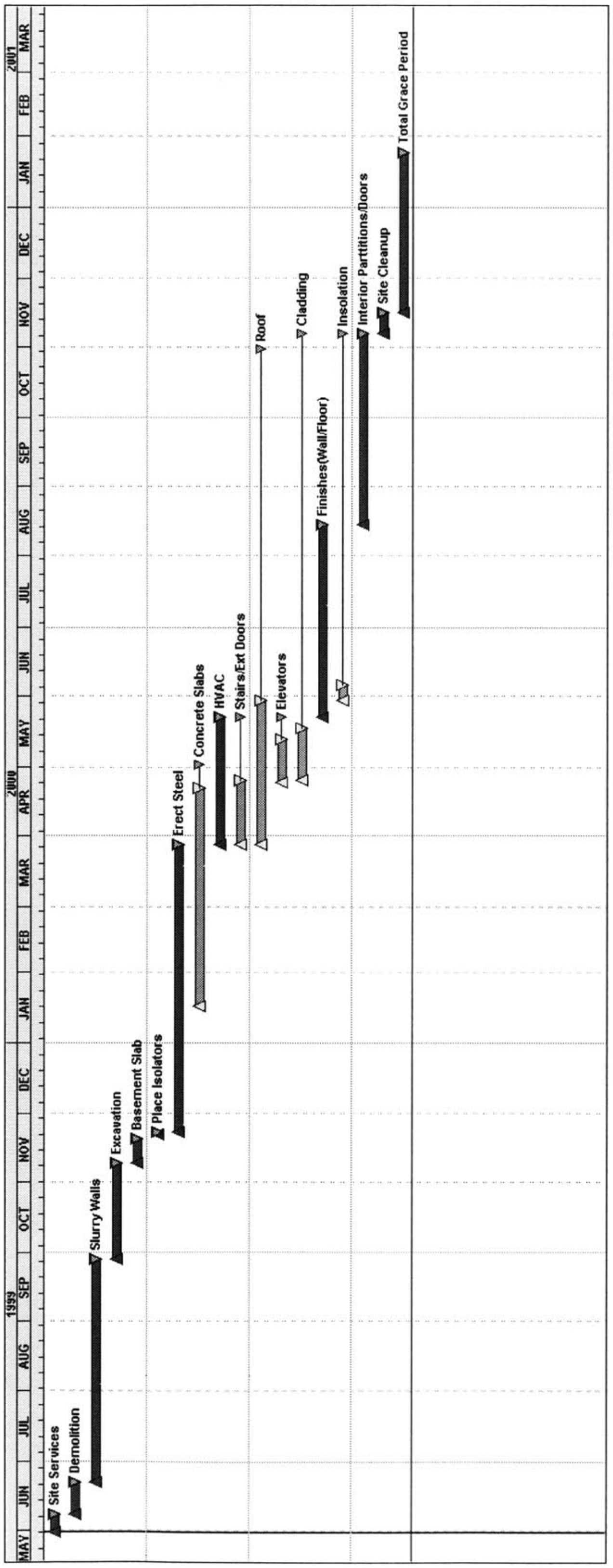
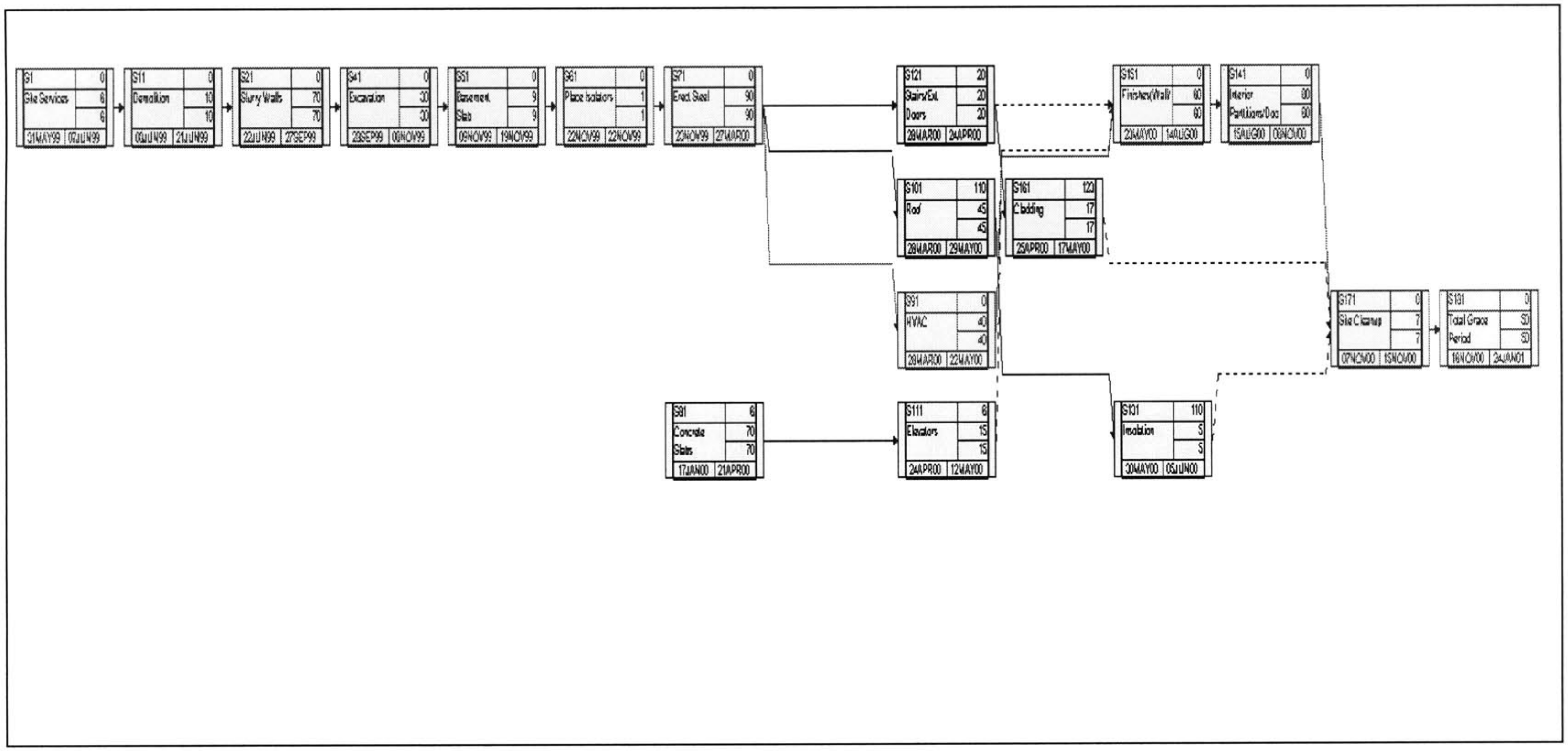

1999
2000
2001
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
Site Services
Demolition
Slurry Walls
Excavation
Basement Slab
Place Isolators
Erect Steel
Concrete Slabs
HVAC
Stairs/Ext Doors
Roof
Elevators
Cladding
Finishes(Wall/Floor)
Insolation
Interior Parttitions/Doors
Site Cleanup
Total Grace Period

Figure 17



Site Services
Demolition
Slurry Walls
Excavation
Basement
Slab
Place Isolators
Erect Steel
Concrete
Slabs
Stairs/Ext.
Doors
Roof
Cladding
HVAC
Elevators
Insulation
Interior
Site Cleanup
Total Grace
Period
31MAY99
22JUN99
27SEP99
28SEP99
09NOV99
19NOV99
22NOV99
27MAR00
17JAN00
21APR00
28MAR00
24APR00
29MAY00
25APR00
17MAY00
22MAY00
12MAY00
14AUG00
15AUG00
24JAN01

Figure 18

Problems Encountered

Problems which can be encountered in the future scheduling and estimating of the project as it moves from conceptual stage to design and construction stages.

1. At the preliminary stage, a grace period was inserted (arbitrarily chosen) at the end of the construction process in order to estimate for delays. When the project progresses into a more detailed stage factors that may cause delays like weather changes that result in bad working conditions, prolonging by subcontractors, and delays in shipment of materials, to name a few, need to be discussed more carefully.

In reality, the estimator and scheduler have a reliable database, which may be used to get more accurate number for the construction process. These include, interpolations drawn from similar projects done in the past, knowledge about the site, as well as experience with the relevant construction techniques. Practice has it that major weather delays are predicted using statistical data and may be estimate to sufficient accuracy so as to eliminate the uncertainty-induced times.

2. Union workers can also be a problem and are a concern that should not be taken lightly. The workers may go on strike and cause delays in work due to problems arising from issues outside the scope of the contracting company.
3. As far as costs are concerned, an increase in the cost of petrol or diesel can adversely affect prices of steel, concrete and many other transport dependant items. Another cost increasing factor to be included, though often anticipated with reasonable accuracy, is inflation.
4. Since this building has several unique components and features, the costs and abundance of these need to be looked into carefully as they may not be readily available.
5. Finally, dealings with high profile architects, as well as the coordination between all parties can be time consuming since each entity is often adverse to responsibility and shares a affinity to appreciation.

The problems stated above have no single answer, but depend on the specific project, site layout and construction systems to be applied. Factors require to be considered using conservative judgement and real construction experience.

6 CONCLUSION

Much importance must be attached to the basic principles of construction management that have been underlined throughout this paper. Not only are they critical but also essential in the process of realization of a successful project. Success may be defined as the effective delivery of a project with respect to budget and schedule, as well as overall control. Besides the technical function that it performs, inherent in this activity is the maintenance of harmonious relationships between all parties. Thus, it may be seen that construction management encompasses more than just the transparent.

In order to achieve these goals, it is certain that a cost estimate and schedule must be prepared in advance. This provides a benchmark against which progress may be measured. It allows deviations from the preset course to be spotted early on, giving sufficient time to the professionals in charge of the operation to take adequate steps. Though historically a project has never followed predetermined plans, it does however enable all parties to judge progress using a single set of rules. This is often instrumental in the allocation of mutually agreed responsibility between all parties and results in the accomplishment of the project.

The case studied in this document was an exercise in the execution of the two most important activities that govern the above-mentioned task, budgeting and planning. It was intended to provide the author hands on experience of the details that are involved in the estimation and scheduling process. These actions have resulted in the crystallization of the ideas that are listed below.

- Good engineering judgement is the key
- Conservative anticipation will be most beneficial
- An estimate or plan is essentially an opinion or assessment
- Accounting of all components and factor is mandatory

This type of a construction management operation can only be fulfilled to greater degrees of detail with adequate experience in the field of construction. At every instance it requires the use of relevant knowledge gained from work done on site. Without such a background, it would be ineffective to 'blindly' use construction data obtained textbooks.

In recent years, construction management has progressed immensely and will continue to form an integral part of every construction project. It is not the author's aim to promote construction management as a savior but to highlight the importance of the components, methods and ideas that constitute the knowledge base of construction management.

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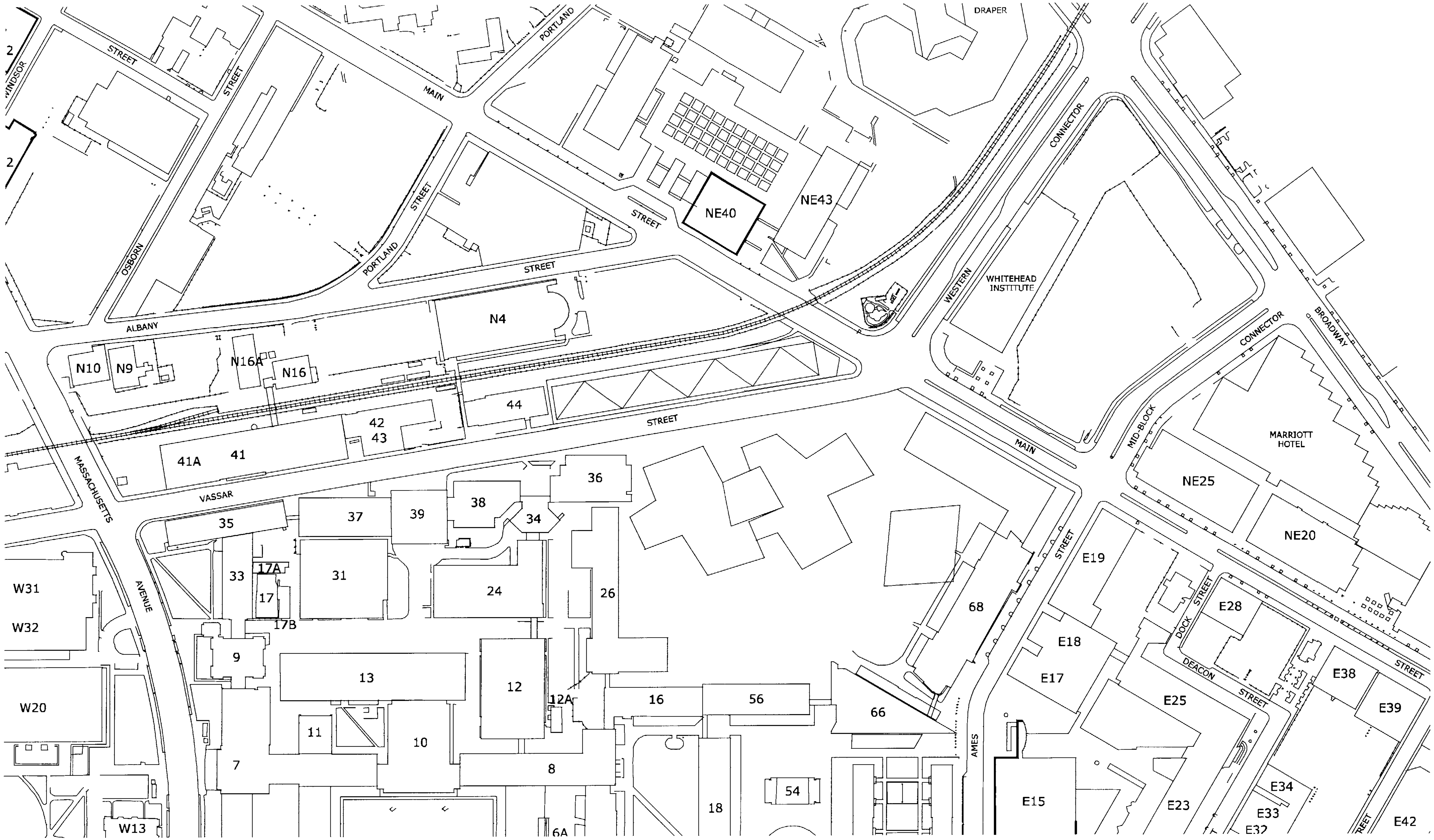
15. **Haley & Aldrich** Edward B. Kinner, Principal (EBK@HaleyAldich.com)

16. **Tate Access Floors, Inc.** (www.tateaccessfloors.com)

8 APPENDICES

Appendix A :

‘Cascade’ conceptual design details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WHITEHEAD INSTITUTE
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W13
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E18
E17
E28
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STREET
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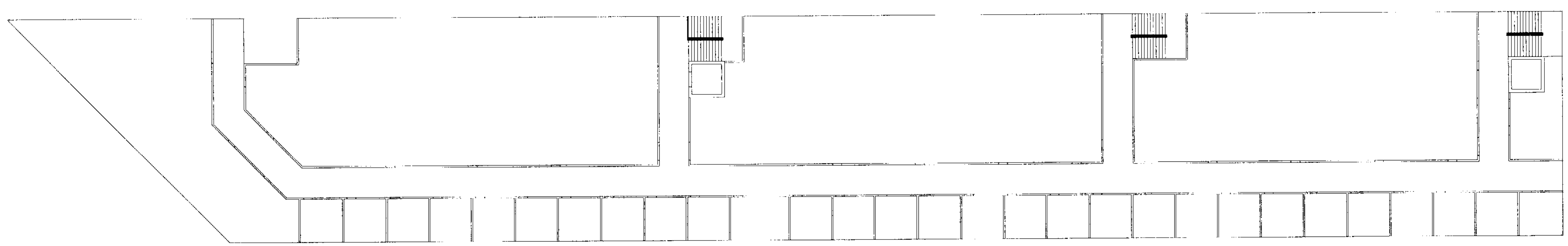
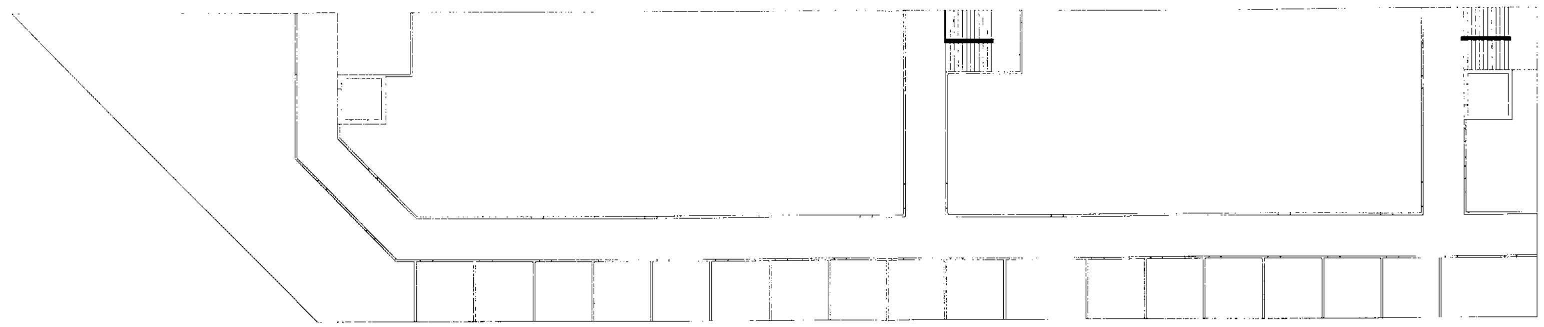
STREET

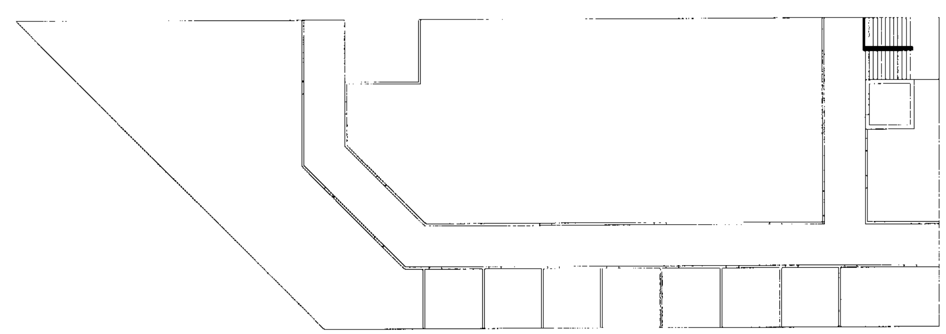
First Floor Plan



Second Floor Plan

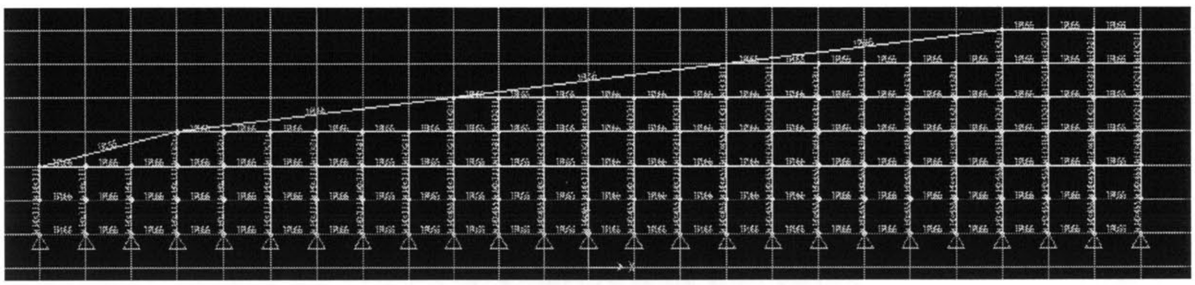


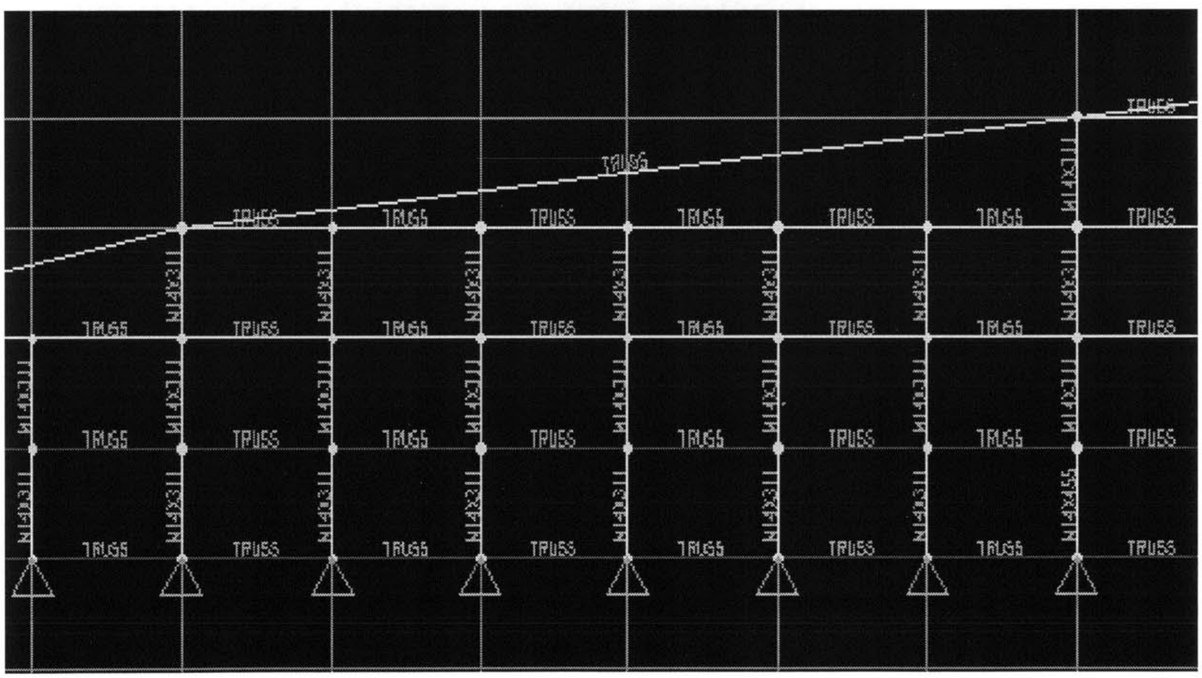
Third Floor Plan

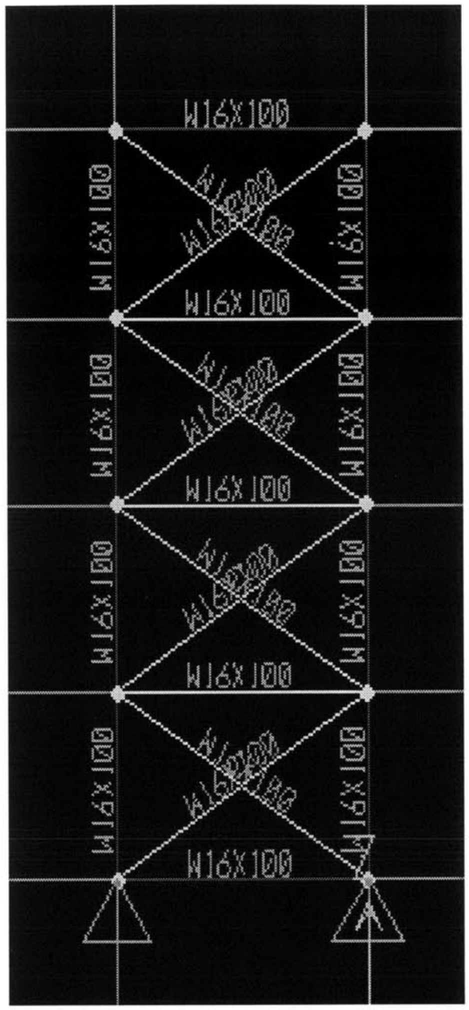


Fourth Floor Plan

Cascade Building Additional Details



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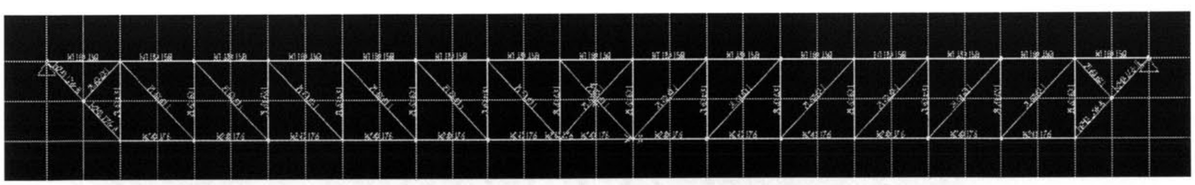

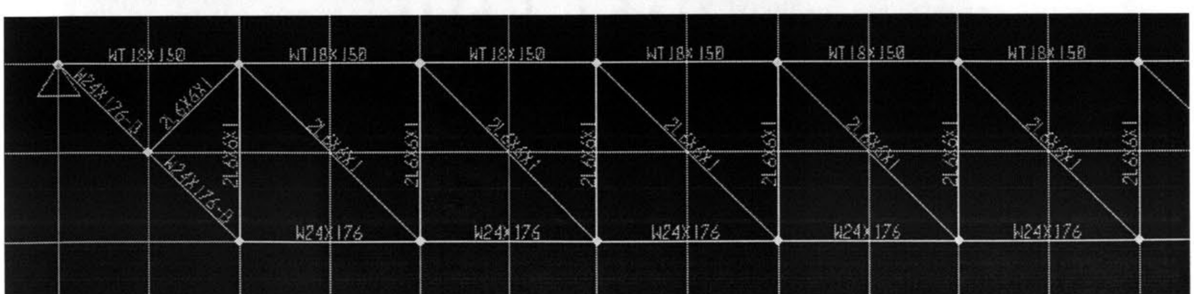
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Appendix B :

Cost Estimation Data

Appendix B

	Unit	Rate($)	QTY	Total
Excavation & Foundations				**800000**
Demolition	cf	$25.50	208500	**5316750**
Slurry walls	cy	5.5	225835.6	**1242095.556**
Excavation	sf	25.7	208500	**5358450**
Slab on Grade				
Superstructure	ton	900	1677	**1509300**
all steel	sf	2	642835.6	**1285671.111**
concrete	per flight	1200	32	**38400**
stairs	per	1000	60	**60000**
base isolators				
Exterior Closure	per door	2000	6	**12000**
Doors	sf	50	76800	**3840000**
Cladding				
Roof	sf	1.82	45000	**81900**
Insulation	sf	25	45000	**1125000**
Roof Coverings				
Interior Construction	sf	25	4500	**112500**
Partitions	per open	10	120	**1200**
Interior Doors	sf	11.7	157500	**1842750**
Floor Finishes	sf	2	45000	**90000**
Interior Wall				
Conveying	per	40000	3	**120000**
Elevators				
Mechanical	sf	29.07	157500	**4578525**
Plumbing				
Fire Protection				
Heating				
Cooling				
Electrical				**915705**
Service & Distribution				
Lighting & Power				
Special Electrical				
subtotal				**28330246.67**
Architect		5%		1666485.098
Contractor		10%		3332970.196
Total				**33329701.96**
Total (Regional Factor)($)				**36662672**
Cost per Square Foot($)				**232.77887**

Appendix B

Total Floor Area	
Floor	Area
0	45000
1	45000
2	33750
3	22500
4	11250
Total	**157500**

Excavation				
Type	**Swell factors**	**Thickness(ft)**	**Volume**	**New Volume**
Fill	1.25	12	622200	777750
Silty Peat	1.2	8	414800	497760
Sand/Gravel	1.15	8	414800	477020
Upper BBC	1.35	4	207400	279990
			1659200	
Total				**2032520 cubic ft**

Mass of Steel		
Item		**lb**
Columns		20682
single Truss	*34950*	
Total Trusses		3564900
Bracing		31500
Beams		72720
Total Mass		3689802
Total Mass(Tons)		1677.182727

8.3 Appendix C :

Scheduling Information

Appendix C

Activity	Unit	Rate	Quantity	Duration(Days)
Demolition				10
Slurry walls	linear ft	20	1390	70
Excavation	cy		0	70
Slab on Grade	sf	45000	45000	(with curing) 10
superstructure				
all steel	ton		1677	90
concrete	sf	2 days per floor + curing(14days)		70
stairs/Ext Doors	per flight	1.5	32	20
base isolators	per	placing only	60	1
Exterior Closure				
Doors	per door		6	
Cladding	sf	4500	76800	17
Roof				
Insulation	sf	9000	45000	5
Roof Coverings	sf	1000	45000	45
Interior Construction				
Partitions	sf	75	4500	60
Interior Doors	per open		120	(combined above)
Floor Finishes	sf	2650	157500	60
Interior Wall	sf		45000	combined above
Conveying				
Elevators	per	0.2	3	15
HVAC (Combined)	sf	4000	157500	40

Note:

All figures have been rounded of to the nearest day. Rates have been used from Means construction data as well as other sources identified in the text and referenced. In some cases, Means data led to unrealistic estimates. Eg: Slurry wall construction data was used from Edward Kinner, Principal, Haley & Aldrich