

DESIGN ASPECTS OF FLEXIBLE INSTITUTIONAL BUILDINGS:
A Case Study of the Main Academic Buildings At MIT

by

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ABSTRACT

The only thing that one can predict with certainty is change. Meeting the changing needs and requirements of academic institutions requires a well defined campus plan. This plan should include an institution's social, institutional, as well as academic goals and objectives. A successful strategy for dealing with these established goals and an unpredictable and uncertain future is to construct facilities which are flexible and adaptable to the changing institutional needs. MIT's success at doing this dates from the construction of the main academic buildings on the Cambridge campus in 1916 and is certain to continue into the future with the development of the latest plans for campus expansion into the Northeast Sector.

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PART I
CAMPUS PLANNING

CHAPTER 1

INTRODUCTION

The Massachusetts Institute of Technology is a dynamic institution. The fields of study are constantly changing and adapting to meet the needs of a changing technological society. The buildings that house the Institute are also constantly changing to meet the progressive needs of changing and expanding curricula, research, administration, and other academic activities. It is believed that 95% of the area of the original buildings on the Cambridge campus of MIT has changed their use since the opening of this campus in 1916. The original buildings include buildings numbered 1, 2, 3, 4, and 10. Figure 1 (all illustrations are found in Appendix A) is a map of the MIT campus buildings and their identifying numbers.

The design of the original buildings, by William Welles Bosworth, was such that all structures would be interconnected to encourage interdepartmental communication and cooperation as well as maximum flexibility for future renovation and expansion. MIT has grown significantly since 1916, but the design and goals of the original buildings seem to endure. Perhaps more than any other buildings on campus, the buildings surrounding Killian Court maintain their original intention of interdisciplinary cooperation and communication and flexibility.

This thesis will examine the reasons why the original buildings proved so successful for their primary purpose and why they have been so flexible and adaptable in their transformation into new uses. In order to analyze the success of campus buildings,

it is first necessary to examine the intent behind those buildings. The intent of academic buildings is captured in a campus master plan. A campus master plan is the collection of available information and experience regarding the goals of the institution, the purpose of the buildings on campus, and the image that an institution wants to portray. This thesis examines the essential ingredients of a campus master plan and the importance of that plan in designing and constructing buildings and facilities which meet the constantly changing needs of a dynamic institution.

CHAPTER 2

ELEMENTS OF CAMPUS PLANNING

Although the idea of campus planning in this country is not new, Jefferson did extensive planning for the University of Virginia, since then the formulation of campus master plans and the methods and criteria for long term planning have become more standardized. The inputs which are considered in developing a long term campus plan include such factors as anticipated enrollment, emerging areas of study, physical plant needs, and expected financial resources. In a 1956 poll, conducted by Richard P. Dober, 66% of the institutions polled had five-year plans, 33% had ten-year plans, and 25% of the institutions had performed a study of space utilization, which is viewed as critical to any long-term campus planning.¹ Today, long-term planning and detailed space utilization plans are common functions of planning and facilities departments at most institutions.

The value of a master development plan for an institution cannot be overestimated. Its value is derived from its detailed account of institutional goals, solutions to architectural problems, a comprehensive summary of past growth and a program of anticipated future expansion. A campus master plan's most important feature is that it serves as the *embodiment of an ideal and a practical guide to the realization of that ideal.*

¹Dober, p. 7.

Campus planning is necessary because of change. The educational process is never stagnant therefore the buildings that house the educational process cannot be permanent, inflexible, or static either. "Instructional space should be encouraging innovation instead of stifling it; it should lend itself to broad modification to conform to the educational programme as it continues to grow and change".²

The nature of change on campuses is varied and extensive. The changes can be based on philosophical, economic, social, and even political trends or ideals. Examples of changes include expanding or contracting enrollment projections, a changing student body, such as women's colleges admitting men, which is usually rooted in economic concerns, or the general trend of an aging student body due to decreasing population of the 18-22 year-old age group. Other examples include changes in admissions policies, changes in curriculum or research programs due to society's needs or institutional philosophy, expanding or contracting faculty population, and the capacity to raise funds, which has significantly different implications depending on whether the institution is private or public.

Another important responsibility of the campus planning department is to provide aesthetically pleasing architecture while avoiding the economy of sameness. Schneider and Peters, two researchers from Stanford University, state the importance of building appearance this way:

²O'Connor p. 134.

“Individual reactions created by the appearance of a building are important. Most of these reactions are psychologically great and difficult to describe”.³

Another author states the importance of aesthetics this way:

“Hidden within the term facilities planning and underlying the total physical planning process is a need to insure a high-quality aesthetic environment. This means that campus planning must concern itself with appearance in new academic facilities. Equally important is the liaison linkage with the Physical Plant Department to minimize, wherever practical, the inclusion of high maintenance buildings or facilities”.⁴

History of Campus Planning

The early institutions in America were initially planned to resemble those in England. The great English universities were characterized by large campuses in central locations and living quarters which housed both students and faculty to promote communication and to set an example of appropriate moral standards. Due to large distances between cities, poor travel conditions, and general lack of funds, neither of these European characteristics were emulated in early American institutions. Instead, several Colonial Colleges were established in various

³ibid., p. 136.

⁴Brewster, p. 11.

locations. These early colleges were mostly recognized for their building types rather than their campus plans, with the exception of William and Mary College.⁵

William and Mary College (1699) in Williamsburg, Virginia is the first example of a rough planning effort for an American college. The college buildings were arranged according to site conditions, with a specified design intention and a program relationship. Because the college was planned at the same time as the city of Williamsburg, the relationship between the city and the college was also planned.

Union College in Schenectady, New York was the first example of a comprehensive planning effort for an American university (see figure 2). The campus, designed by Joseph Jacques Ramee in 1813, differed greatly from the traditional campuses of Oxford, and Cambridge, England which, up to then, had served as model campuses. The campus plan of Union College was more open and inviting and showed a regard for surrounding landscape in the siting of the buildings. The master plan for Union College was followed by the College up to the 1960's when the development of the eastern campus broke away from the original plan.⁶

The first, and probably most famous, example of campus planning is Thomas Jefferson's University of Virginia (see figures 3 and 4). Jefferson was a true master planner for he took on the responsibility of selecting the site, designing the buildings, preparing the drawings and specifications, supervising the

⁵ibid. p.14.

⁶Dober, p. 21.

construction, devising the curriculum, selecting the teachers, and even procuring the funds from the Virginia Legislature. His concept of a secular and non-denominational education based on science and technology was revolutionary and inspired not only the founding of MIT but the development of the campus plan for MIT's Cambridge campus. Jefferson is credited with "giving rational form to an educational program, and... its consideration of site and functional arrangements".⁷

Modern Campus Planning

The importance of campus planning cannot be overestimated. The goal of a campus plan is to provide an appropriate environment to encourage the educational process. A successful campus plan should not only incorporate physical facility needs, but ideological goals as well. The campus plan should illustrate the goals and objectives of the institution and provide buildings which are functional and adaptable to change and expansion. It should offer a method of evaluation and a means of translating the educational program into physical facilities, and, most of all, it should do all this in an aesthetic and pleasing manner.

Successful campus planning requires a broad understanding of how a campus really functions and how the buildings will really be used. To acquire this information takes time and careful study of the existing facilities on a campus and an historical analysis of past campus experiences. Information needs to be gathered about the

⁷ibid., p. 22.

interaction among faculty and students, daily life on campus, educational and social needs, past complaints or praises, changing institutional goals, pedestrian and vehicular circulation, interaction with surrounding neighborhoods and financial considerations. This information cannot be gathered solely by a short-term consulting architect or planner, but must be continually observed and defined by the administration, faculty, staff, and student body. This requirement illustrates the essential need for an experienced campus planner who can interpret the 'needs' of the institution and translate them into an effective campus plan:

“The capacity of a university or college to plan varies according to a great number of factors. Most important among these is the historical attitude of management in dedicating itself to a systematic planning process. Because the establishment of process and procedures, and the documentation of [the] plan, is so time consuming, management, which has only recently made a commitment to planning, will most likely be operating at a disadvantage.”⁸

Herein lies MIT's great advantage. MIT has been consciously planning and replanning the campus since the early 1900's. Although the early plans were not as detailed as the more recent ones, they still incorporated the major elements of a focused and well directed campus plan.

⁸McKinley, p. 3.

MIT is different from many institutions in that planning has been a part of the Institute since the conception of the Cambridge campus. Many colleges and universities stumbled into planning as they experienced the ill effects of rapid uncontrolled growth; buildings were sited in a hodge-podge fashion with little regard for site characteristics, overall campus coordination, and aesthetics.

The process of developing a campus plan includes interpreting, organizing, and evaluating information from many different sources. The first ingredient is academic planning. A plan for a educational facility can only be developed once a long range academic plan has been established. The necessity of detailed academic plans seems obvious but many schools try to produce campus plans without them. Accurate academic plans offer invaluable information about required building services, expected growth of departments, expected student, faculty and staff population size, interaction among different departments and buildings, rates of growth or anticipated change. A key characteristic of an academic plan is that it must be functional and up-to-date. Without an established academic plan, the architects and engineers will be responsible for dictating the the academic plan and this is obviously a backward process.

In addition to an academic plan, an institutional plan must also be formulated. An institutional plan will incorporate all the goals, intentions, and criteria that an institution desires to meet above and beyond academic performance. This plan will include things such as, to use business terminology, the 'target market' of the institution. This will include ideals about the type of facilities and services an institution wants to offer, the type of students, faculty, and staff

the institution wants to attract, and how it perceives that it will achieve those goals. A critical factor in developing an institutional plan is defining where an institution wants to be in the future. Accurate projections and control of growth are essential to the development of a successful campus plan. A campus plan should be a working tool not just a architectural drawing etched in stone.

Another important aspect of a campus plan is the campus utility plan. Often generated and maintained by the physical plant department, it is a valuable tool in developing a campus plan. On campuses, due to desired aesthetics, most utilities are run underground. Because mechanical service systems are so expensive, it is imperative that they be considered when expanding an existing building or building a new facility on campus. The utility plan should not dictate the campus plan, but it should always be a referenced when considering changes. Likewise, it is imperative that a utility plan be kept up to date to accurately reflect the situation at any given time. Advance planning in this fashion can save money in the future. For instance, extra conduits and future utility lines can be incorporated into the campus plan to reduce costs of excavation and placement in the future. Another critical factor of planning, which is usually handled by the physical plant department, is the consideration of future maintenance costs of new and renovated facilities.

Another key to a successful campus plan is the ability to adapt to changes. No sooner will a new building be occupied than the first request for changes will be received by the planning or physical plant department. Planning for flexible, adaptable buildings will

result in renovations with minimal cost and maximum efficiency. A campus master plan is not a static blueprint for the future, but a continuous process of campus planning. “A comprehensive development plan or master plan carefully prepared, properly approved, and correctly used can mean the difference between a disorganized campus and a pleasing, functional grouping of buildings and spaces”.⁹

⁹Brewster, p. 54.

PART II
PLANNING AT MIT

CHAPTER 3

THE HISTORY OF MIT

The Massachusetts Institute of Technology was founded by William Barton Rogers in 1861, the year of its incorporation and land grant by the Massachusetts legislature. The Institute, originally referred to as “Boston Tech”, was located in the Back Bay on Boylston Street between Berkeley and Clarendon Streets (see figure 5). The school shared a block with the Boston Society of Natural History which is still standing today and is occupied by the store Louis (previously the location of Bonwit Teller). Boston Tech “officially” opened to students in 1865, four years after its incorporation, but classes were not actually held in the new building until 1866.

The original curriculum included programs in applied mathematics, physics, geology, chemistry, engineering, architecture, English literature and modern languages. The engineering courses included civil, mechanical, and mining engineering. In 1873 there was an expansion of the professional courses offered at Boston Tech and the courses were numbered the following way:

<u>Course Number</u>	<u>Description</u>
I	Civil and Topographical Engineering
II	Mechanical Engineering
III	Geology and Mining Engineering
IV	Building and Architecture
V	Chemistry
VI	Metallurgy
VII	Natural History
VIII	Physics
IX	Science and Literature
X	Philosophy

Perhaps the most significant distinction between Boston Tech and other universities of the day was that MIT *emphasized hands-on laboratory experience in addition to traditional classroom instruction and rote memorization.* This becomes particularly evident with the construction of the new buildings and the allocation of space to engineering laboratories.

Boston Tech's enrollment and reputation grew steadily throughout the end of the nineteenth century. By the turn of the century there were nearly 1300 students enrolled and a faculty of 56. The enrollment had continued to grow at a steady pace and it was evident that the relocation of MIT to bigger quarters was necessary.

Several alternatives to the space problem were considered. These alternatives included merging with Harvard, relocating to property in Jamaica Plain, and even creating an island in the middle of the Charles River on which to house the Institute. The option of moving to Cambridge without affiliating with Harvard seemed slight since, it was believed, that the City of Cambridge did not want to allocate any more tax exempt property within the city limits. The merger with Harvard University was vehemently opposed by a majority of faculty and alumni, but the Corporation voted to do just that in 1904. The most enticing aspect of the merger, from MIT's point of view, seemed to be economic, but when the Supreme Judicial Court of Massachusetts ruled that a merged MIT could not sell their existing land grant buildings to raise money for the construction of new buildings in Cambridge the deal fell through.

MIT continued pursue the search for a new location for the Institute. The City of Springfield, MA, inspired by local alumni, offered the Institute a 30 acre site on the Connecticut River. Upon hearing of this development, the City of Cambridge changed their stance and agreed to allow MIT to locate within the city even if it meant more tax exempt land. The Institute to be sited in Cambridge became commonly referred to as "The New Technology".

The Institute proceeded to acquire 46 acres of land east of Massachusetts Avenue from 35 different property owners. The majority of the \$775,000 purchase price for the land came from T. Coleman DuPont in a gift of \$500,000. Other significant contributions were made to the fund for the construction of the New Technology. There was no more significant contribution than that made by George Eastman, the founder of Eastman Kodak. Mr. Eastman anonymously donated \$2,500,000 for the construction of the new buildings. The man responsible for the successful fund raising efforts of The New Technology was Richard Cockburn Maclaurin, President of MIT from 1909-1920.

Once the Institute was quite sure it could raise the required funds, the site selection process and a study of the design of the buildings was begun. John R. Freeman, a civil engineering graduate in the class of 1876 and an internationally recognized engineer and member of the corporation, volunteered to perform a study of all the great technical schools in the United States, Canada and Europe and to develop a design for The New Technology. His findings and the development of the Cambridge campus is discussed in the next chapter.

Once the Cambridge campus was completed MIT enjoyed a twenty-five year period of stable growth (see Table 1 in appendix B) and increased national and international recognition as a leading technical school. The institute continued to maintain its objective of offering students hands-on laboratory experience and training which would prepare them for applied science and engineering positions in private industry.

The Division of Industrial Cooperation (DIC), the MIT department which supervised and coordinated all research work prior to the 1940's, was what established MIT as a major Research Institute. The research programs were not as specialized, proprietary, nor as lucrative as they are today. Often research was not funded directly or exclusively by one manufacturer, but from the DIC which was responsible for fund raising and information dissemination among a variety of sources.

The advent of World War II had the most significant impact on research programs in the history of MIT. Prior to WWII a negligible amount of research monies were supplied by the federal government, since the 1940's, the federal government has been a major source of research funds for the Institute. The first WWII research program at MIT, funded by the War Department, was the Radiation Laboratory which was responsible for the development of radar. Numerous other programs followed and MIT responded by constructing a dozen or so buildings which were designated as "temporary war research laboratories". These buildings were planned with a sense of urgency and the specific purpose of war research in mind. They don't reflect the same type of planning criteria upon which the rest of the

Cambridge campus is based. Building number 20 is an example of one of these facilities which is still standing (although this building is scheduled to be demolished under the development plan for the Northeast Sector).

CHAPTER 4

HISTORICAL DEVELOPMENT OF CAMPUS PLANNING AT MIT

Since the time at the turn of the century when the administration of MIT first realized that it was about to outgrow its quarters in the Back Bay, the long detailed process of campus planning for the Cambridge campus began. The process began with the site selection process, then, once the site was established, John Freeman and William Bosworth performed detailed studies which not only resulted in a successful campus plan, but also embodied all the criteria which later became recognized as the essential features of flexible institutional buildings.

Site Selection

Prior to the construction of the Cambridge campus came the difficult process of site selection. A committee was formed to suggest and evaluate possible site alternatives for the Institute. This committee established the basic criteria of site selection so that the chosen site would impart the proper “cosmopolitan character” to the Institute.

“Students [are] drawn from the ends of the earth and [are] widely distributed over every state in the Union. For its size the Institute is more representative of America as a whole than any other institution in the country. The function that it plays is mainly a national one. It does, however, play a peculiarly important role in this particular locality. It educates a large number of

young men who must live at home, either within the metropolitan area or within striking distance of Boston by railroad. To fulfill its national function, the Institute might be located anywhere, but for the benefit of those that live near the Hub, it must be situated as conveniently as possible - must be easily accessible by car from the railroad stations, and from the various parts of the metropolitan district, the suburbs being in this respect no less important than the city itself. It is this fact which excludes a country site for the Institute as has sometimes been suggested for it".¹⁰

As many as fifteen sites were suggested, but only three were considered seriously. These three sites included the Fenway in the proximity of Kenmore Square, the Allston Golf Club, and the Charles River site in Cambridge.

The Fenway site satisfied several of the criteria of site selection including proximity to Boston, easy commuting by rail and car, and enough space for the Institute to eventually expand. This site also had an advantage because it was appealing to the people who wanted the Institute to remain in Boston. In the plan for this site, it was envisioned that the Institute would be surrounded by other public buildings and that the area would become a civic center. Unfortunately the site had poor soil conditions, and it was believed that the price of foundations could become cost prohibitive.¹¹

¹⁰MIT Archives, AC 13, Box 3, File #85.

¹¹MIT Archives, AC 13, Box 3, File #74.

The second alternative was the land occupied by the Allston Golf Club. It was attractive because of the price, but there was serious opposition by several members of the committee and alumni. The committee felt that the site was too residential and the alumni voiced the problems of the proximity to the B & A railroad. The adjacent freight yard would cause a smoke nuisance, noise problems, and vibrations which would interfere with delicate laboratory experiments.¹²

The Cambridge site, the third alternative, had many advantages. These advantages included that the site was substantially undeveloped, offered suitable soil for foundations, and was close to Boston and the proposed Subway in Cambridge. The Cambridge site had many proponents who included several prominent citizens, the Taxpayers Association, the Cambridge Club, the Presidents of the Cambridge Trust Company and the Central Trust Company, and the Mayor of Cambridge, William F. Brooks. Harvard University, which had originally objected to the Institute's relocation to the Cambridge site, withdrew its objections in March of 1911 due, mainly, to the pressure put upon them by the local citizens.

The site selection committee went on to select the Cambridge site because it:

“...is remarkable for its accessibility. It is already easily reached from all points of the metropolitan area, and when the Cambridge subway is completed,

¹²MIT Archives, AC 13, Box 3, File #74.

will be even more accessible, especially from North Station. It comprises an area of just about fifty acres, has a frontage of a third of a mile to the Esplanade on the River Bank, of over a thousand feet to Massachusetts Avenue to the Shoe Exposition Building and from the Esplanade to the Boston & Albany Railroad tracks. It is all level land capable of being advantageously developed for building purposes with admirable exposure of light everywhere".¹³

Planning the Main Academic Buildings

Freeman's Approach

John Ripley Freeman, a graduate of MIT and an engineer and industrialist by trade, undertook the design of the new buildings for MIT (see figure 6). Freeman believed that the design of The New Technology was "1/5 architecture and 4/5 a problem of industrial engineering".¹⁴ Freeman was also a man of great instinct and foresight. Although he never formally studied to be a planner, his main concerns regarding the construction of the new buildings are those that are still concerns of institutional planners today. His main concerns were cost, efficiency, and adaptability. He executed his extensive international study of institutional buildings much as it would be done today -- by researching existing buildings and historical data and developing a complete building program.

¹³MIT Archives, AC 13, Box 3, File #85.

¹⁴Aldrich.

Freeman as Planner

Freeman's insight into the anticipated future needs of the buildings and the changes that they would have to undergo to meet those needs, came from an extensive study of the existing MIT buildings in the Back Bay. From a comparative study of the old MIT buildings to the new proposed buildings Freeman writes;

“It is of interest to compare the area of the present Institute buildings with that of the proposed buildings, and to note ...that in the planning for an increase of about 20% over the present number of students in all departments, an increase of 200% in the floor area is called for.”¹⁵

Freeman compiled information proposed by professors regarding the housing and fitting up of their respective departments. He then compared this compilation of building and equipment needs with that of a survey of forty other educational institutions, both in America and in Europe, which he had studied. This survey included measurements, photographs, building plans, and building and fit-up costs. The costs were represented as a square foot cost for each type of facility and specific use.

Freeman wrote detailed reports analyzing the difference between American and European academic building clusters. The U.S. groupings of buildings and the arrangements of departments is very

¹⁵Freeman, Study No. 7.

different from that in Europe. American campuses, in general, were characterized by buildings with completely different architectural styles scattered over a campus. Academic departments are independent and physically separated from one another. Freeman realized one of the major drawbacks of this isolation of buildings was that “undergraduate students must rush from class to class [and therefore lose] the opportunity for personal contact with the lecturer or asking questions”.¹⁶ Freeman contrasts this with European campuses such as Munich, Berlin, or Birmingham where buildings are “housed in a single, connected group, closely resembling the arrangement for the best modern factories”.¹⁷

Freeman went on to explain this phenomena by recognizing that U.S. universities are often built one building at a time as funding allows. Oftentimes, when a significant donation has been made for the construction of a new building, the concern with creating a fitting monument to the donor in gratitude for his/her generosity supersedes the consideration of the intended use of the building. Freeman gives many examples, but perhaps the most effective for his argument is the Rogers and Walker Buildings on the Boston Tech Campus in the Back Bay.

Freeman had been asked by Crafts, then president of MIT, to critique the existing buildings in Boston. Freeman was very critical of the existing buildings. He reported: “unit stresses, fire hazards, and lack of sanitary precautions sadly at variance with what it is

¹⁶ibid.

¹⁷ibid.

presumed is taught to the students in those buildings”.¹⁸ In addition to Freeman’s criticisms, he goes on to make suggestions on ways to improve the usefulness of the new buildings which will be discussed later in this paper.

Freeman was a forward thinker and understood the dynamic nature of the Institute. He wrote:

“In the days when the writer was a student at Technology, educational departments for Electrical Engineering, Electro-Chemistry, and for Biology as applied to public health were not dreamed of. Nor had Chemical Engineering and Naval Architecture been thought of as giving scope to separate departments. It would be short-sighted to assume that the developments of the next 35 or 40 years will not be equally great, and it is plain beyond all doubt or question that this lot of less than 50 acres, which to begin with is far smaller than the campus of many of our American Colleges, must be scrupulously conserved and the type of buildings should be selected with a view to economizing the area of this land to the utmost”.¹⁹

In order to accommodate future growth of the Institute, Freeman suggested developing a program of bonding adjacent properties for the anticipated expansion. He suggested doing this by

¹⁸ibid., p. 12.

¹⁹ibid.

securing deeds from the adjacent land holders and leasing back the use of the land for twenty five to fifty years or more. This suggestion was valuable for several reasons. It prevented the Institute from having to purchase additional land outright with already limited construction funds, ground rents offer safe and profitable investments, and the annual cash outlays could be small if a fund were set up such that it matured at the end of a twenty five year lease.

Freeman anticipated the use of the campus as a summer school during the regular summer vacations. He believed that Boston had much to offer and would draw large numbers of serious students and teachers during the summer months. He believed Boston's appeal included a good location near the shore, galleries, museums, libraries, relatively cool summer weather, and beautiful parks. In order to accommodate this use during the summer months Freeman's proposed design incorporated the cloister and cloister gardens for excellent ventilation on hot and humid days.²⁰

Freeman as Designer

Freeman's overwhelming concern was with economy and efficiency. He severely criticized architects whose designs emphasized exterior design and detail and all but overlooked "interior and efficiency" considerations. Freeman was especially concerned with mechanical efficiency, safety against fire, and window lighting and ventilation. Freeman was President of Factory

²⁰ibid. p. 20.

Mutual Fire Insurance Company of Providence, RI, hence his particular attention to fire safety.

Freeman, thinking as an industrial engineer, was focused on the interior effectiveness and cost efficiency of the buildings and designing the perfect “single detail which should be repeated a hundred or a thousand times in a building group, thus reducing the construction cost to the lowest possible terms”.²¹

In order to develop a program for the new buildings Freeman carefully calculated each departments’ needs and formulated them into specifications for units of construction. These units of construction are consistent with what the Planning Department now calls “flexible building modules.” Freeman wrote, “One provision in this arrangement was that walls between units were not to be used for support: thus it would be easy, as need arose, by removing them to put several units together to form a large room, and also to reverse the process”.²²

Freeman determined that the most cost effective method of construction would be to duplicate that of contemporary factories and office buildings “wherein a unit section is worked out with great care and most thorough attention to detail and then this one form is repeated as many times as possible in the final structure. The cutting of a 1000 pieces of steel or a thousand forms, all to the same dimensions, and the making of every door casing, every window casing, and every sash, so far as possible, of precisely the same

²¹Freeman, Study No. 7.

²²Pearson, p. 134.

dimension, of-course, greatly lessens the cost and quickens the work of erection".²³

Freeman was also concerned about keeping costs down and working within the budget of \$2.50 per square foot for a buildings of 1,000,000 square feet. He suggested using prefabricated concrete panels for the facade to keep costs down. At the time there was no existing technology for good quality, prefabricated architectural concrete but Freeman believed the material could be developed with a "faithful study of the subject" (see figure 5).²⁴

Freeman, still studying the project on a volunteer basis, proceeded to develop a complete set of drawings for the proposed buildings. The buildings comprised 1,000,000 square feet of floor area. This figure was was arrived at for two reasons, it not only was within the financial restraints of \$2,500,000 or a square foot cost of \$2.50, but it also approximated the area requirements proposed by the faculty in his study of building and equipment needs.

Freeman thoroughly examined building material and construction method options in order to stay within the budget of \$2.50/square foot. Freeman suggested the use of reinforced concrete for the structure. At the time, this type of construction was used mainly for factory and office buildings, but even in those applications it was not all that common. Freeman's study of this material produced cost estimates of \$1.20 to \$1.59 per square foot. Since no other academic buildings had been built from this material, no cost estimates were available for similar structures. The

²³ibid., p. 16.

²⁴ibid.

buildings that produced the estimates of \$1.20 to \$1.59/square foot were “built with a rougher quality of finish and with a closer spacing of columns and therefore cheaper floor plans than would be best for our lecture rooms and laboratories”.²⁵

Freeman succeeded in incorporating all the necessary elements of flexible institutional buildings, except, perhaps, the appropriate aesthetic quality. Following is Freeman’s theory on designing an efficient building:

“...the problem must be worked out from the inside. First of all, we must obtain a flood of window light; Second, a flood of fresh air under perfect control; Third, an efficiency and avoidance of lost motion by student and teacher, equal to that which obtains in our industrial works. And fourth, the consideration of the psychology of student life, the cultivation of the social instincts, the development of personal contact, must strongly control the layout of the very masonry. Some fruits of this consideration will be found in the serious attention given to cloisters, cloister garden and to unusually ample corridors and entrance halls.²⁶

Freeman was very concerned with adaptability, changes in occupancy and future use of the buildings. Again, he used this

²⁵ibid., p. 16.

²⁶ibid., p. 13.

argument to support his proposal of building in standard unit sections. Freeman's standard unit section consisted of:

"windows, piers, columns and roof, within which curtain walls of light weight could be put up in any convenient position so as to take in a room either one, two, or three windows, as might be required of a particular use, or so that these partitions can be shifted during the next hundred years as new developments come. ...Flexibility for change and extension of departments must be a controlling feature in the type and arrangement of the buildings to be constructed forwith, and no man can today tell at just what point of the organization the greatest change will come".²⁷

Mr. O. Robert Simha, Director of Planning for MIT, explains that Freeman's planning efforts were so successful because he approached the project "completely backward". He developed a program strictly according to the academic needs of the Institute and his best projections of future needs. Because Freeman was not an architect, but an engineer, he was primarily concerned with the functions of the Institute's buildings instead of their exterior appearance. This engineers approach, Mr. Simha explains, is one of the main reasons for the enduring success and adaptability of the main academic buildings on campus. Freeman's invaluable

²⁷ibid., p. 17-18.

contribution of adaptable and flexible buildings have become the MIT standard against which other MIT buildings are judged.

Maclaurin's Decision

Although impressed with Freeman's research, Maclaurin didn't agree that the new buildings of MIT should appear utilitarian. In fact, Maclaurin wanted buildings of a monumental quality and believed that MIT students "should receive the education of beautiful surroundings, ..., and that the appearance of the buildings should be in every way adequate to the magnificent site and to an institution of learning which was to be first in its field".²⁸ This is perhaps Maclaurin's greatest contribution to MIT. Of course, he will always be remembered for his ability to raise the much needed capital for MIT's move to Cambridge, but his insistence on "monumental" buildings makes him responsible for the aesthetically pleasing and timeless style of the buildings we see today.

Maclaurin then proceeded to hire an architect to design the new buildings of MIT. William Welles Bosworth, class of 1889, was selected as chief architect under the review of John Knox Taylor, Head of the Architecture Department. Freeman strongly objected to the selection on the basis of Bosworth's inexperience, but the selection withstood the criticism.

²⁸ibid.

Bosworth's -Approach

William Welles Bosworth graduated from Marietta Academy in 1886, and from MIT in 1888. Upon graduation he apprenticed with a Boston architectural firm. He then joined the staff of an architectural magazine where he lead a research trip to Europe. Bosworth then moved to France where he received a doctoral degree at L'Ecole des Beaux Arts in Paris. After this, Bosworth returned to the United States and enjoyed success as both a commercial and residential architect. Years after the construction of MIT, when Bosworth returned to Paris, he was selected to direct the restoration of the Palace of Versailles, next to MIT, perhaps his most important work.

Upon the death in 1912 of Professor Despardelles, the head of MIT's School of Architecture and the person in charge of the development of plans for the new buildings (for Despardelles' design see figure 7), Freeman offered his services to prepare a working plan for the project. Freeman's offer, as was discussed above, was accepted and he spent a year developing an extensive program and working drawings for the new buildings. However, when it came time to select a chief architect for the project, President Maclaurin overlooked Freeman and selected Bosworth instead. Following is the telegram between Freeman and Maclaurin and the ensuing reply from Bosworth:

“Richard C. Maclaurin
Massachusetts Institute of Technology
President

- By way of presenting something definite to [the] executive committee and because of my fears that efficiency may become sacrificed for exterior appearance as in many other colleges which I have examined, I will agree to furnish all service of design and supervision regularly covered by architect's commission for not exceeding one half the regular architectural commission and possibly for only one third -- and will include employment of competent consulting architects upon decorative and artistic features provided by plans already submitted are in general satisfactory to executive and will agree to have working plans ready for builders to begin within four weeks after general arrangement is accepted by committee...[signed] John Freeman"²⁹

Although Maclaurin never replied to Freeman's telegram, Bosworth's subsequent letter certainly must have clarified the situation for Freeman:

"Dear Mr. Freeman:

Doctor Maclaurin and I have just signed our agreement and I wish in undertaking this work to say to you that whoever did it would be under very great obligations to you to the exhaustive way in which you have prepared the ground. I have been greatly impressed by the [cursory] view of your report and

²⁹Lawrence, p. 15.

shall no doubt [see] more and more to respect in it as I study it further. Hoping that I may have the pleasure of meeting you at a not distant date to talk over "the New Technology," I am very sincerely yours, [signed]

William W. Bosworth

New York, Feb 17, 1913"³⁰

It can only be surmised that Maclaurin chose Bosworth over Freeman for personal reasons. It is true that Maclaurin had voiced opposition to Freeman's "factory looking" buildings, but if other conflicts were not involved then perhaps a compromise could have been worked out regarding the architectural design of the buildings' facades. Freeman even offered his services on a collaborative basis, but it was clear that Maclaurin wanted Bosworth to be fully in charge of the project.

Although Maclaurin's treatment of Freeman seems somewhat callous, in retrospect, it is easy to appreciate Bosworth's contribution. The grand facade, the great dome, and the classic architectural details of the main academic buildings at MIT, which are major part of its enduring attraction and appreciation, would perhaps have been compromised if Freeman's more utilitarian plan had been accepted. Bosworth's contribution to the master plans of MIT did not end with the construction of the main academic buildings. Bosworth was retained as a consultant to MIT's planning department through the 1950's. He was especially concerned about

³⁰ibid. p.15.

open space and the development of Killian Court as he had originally envisioned it with sculpture, fountains, elaborate plantings, and stonework, not unlike the Palace of Versailles. These plans were never realized.

According to several articles written at the time, Bosworth approached the the design of the new buildings at MIT purely from an architectural standpoint. He, in fact, did incorporate several of Freeman's ideas, but was solely responsible for the exterior architectural details, selection of materials, the scheme of courtyards, and the principal feature of the dome over the main entrance at the north end of the main court. Bosworth's plans also incorporated drawings of anticipated expansions which were to the north in almost a mirror image of the original buildings except for another arm of the structure jutting out directly from behind the dome to the north (see figure 8). According to an article in the *Architectural Review*, September 1913, it is easy to see that Bosworth did in fact incorporate several of Freeman's ideas, even if it appears that he claims them to be his own:

“The main, or academic, group was located near Massachusetts Avenue, so that a view into the courts could be obtained from the bridge; and the adjustment of areas to requirements left about one half the land at the east for the students' group of dormitories, gymnasium, Walker Memorial, tennis-courts, and athletic field. This scheme, having been presented in the preliminary sketches reproduced, and accepted by the Executive Committee,

tabulations were next made of the number of students in each course for each of the four years, and the interrelations of courses, to determine the most convenient location for the various departments. For instance, General Studies, being almost a separate school used by all first-year students, could be somewhat isolated from the special departments; though second-year students, who continue with General Studies, take principally Chemistry; as do all first-year students. General Studies was therefore located at the front to the secondary court, to the east and nearest the dormitories. The Chemistry Department was next located adjoining General Studies. On the opposite side of the group, Architecture was similarly placed, with Civil Engineering adjoining it. Mechanical Engineering and Hydraulics naturally followed Chemistry. Electricity was placed in the rear of the dome, with ample room for future expansion; and Physics between Electricity and Chemistry, with which it is naturally allied. Mechanic Arts, being noisy, was located at the extreme northwest corner of the group, in connection with the department of Mechanical Engineering. Biology, being independent, was placed where the symmetry of the plan offered a suitable location.

- The Pratt School of Naval Architecture is arranged to form a complete unit along Massachusetts Avenue, though connected at each end with the main group. This building will also contain the large auditorium. The library is beneath the dome, and the Administration Offices are located adjoining the central portico on its western side".³¹

At the time, Bosworth's design of the new MIT buildings stood out for two main differences from the customary design of academic institutions. The first difference was that instead of "arranging the buildings along about one axial line, two axial lines, both at right angles to the river, have been established".³² The other "radical departure" from traditional institutional architecture "has been the the substitution of one enormous structure, providing space for all departments under a continuous roof, for a number of individual buildings, each devoted to one or more studies".³³ This design, of course, was first proposed by Freeman. There is no evidence that Bosworth attributes this concept to Freeman, nor the concepts of flexible "units of construction" which were the precursors of modern "flexible building modules".

The Architectural review of September 1913 goes on to applaud Bosworth for this concept of connected buildings.

³¹Architectural Review, September 1913.

³²ibid.

³³ibid.

“After consideration, there can be no doubt that the adoption of a single building to house all classrooms and departments was the practical solution. This makes it possible to pass from class to class without going outdoors, and with a minimum loss of time”.³⁴

Almost these exact observations were noted by Freeman in his study completed six years earlier. The same article also recognizes the advantage of non-bearing interior partitions for reconfiguration of the interior space, “...the present scheme provides internal partitions of a temporary nature; so that classrooms can be enlarged, or made smaller, as necessity demands; and all large lecture-rooms will remain within easy reach from even the most remote angles of the building”.³⁵ This is another example of a solution which was suggested first by Freeman, and later was adopted by Bosworth in the final design.

In retrospect, it is easy to appreciate the collaboration, however unintentional or unacknowledged, between Bosworth and Freeman. This collaborative effort produced a campus unlike others being constructed at the time. As Freeman had stated early on in his study, he had no intention of creating a campus which was nothing more than a series of stand-alone buildings, each unique in character and architecture, and built as monuments to the largest financial contributors. The cooperative effort between engineer and architect

³⁴ibid.

³⁵ibid.

resulted in the best of both disciplines. The interior spaces are functional, flexible and have stood the test of time. The exterior architectural features are classic and timeless, the great dome is still the most outstanding architectural feature on campus.

The timing of the collaboration also had a great deal to do with the success of the project. Freeman harbored resentment for Bosworth because of Maclaurin's choice of Bosworth as the chief designer. Had the two been required to work simultaneously, it is doubtful that they could have overcome their differences because of their strong personalities and their differing views on the relative importance of functional versus architectural design. Because Freeman had already completed his extensive studies and Bosworth recognized their importance while undertaking his task of architectural design, the resulting plan exemplified the importance of the collaborated effort. Had it not been for Freeman's extensive studies and reports, Bosworth may never have implemented the invaluable concepts of flexible building modules or interconnected buildings. Nor may he have taken into consideration the importance of the structural bay size for superior ventilation and penetration of natural light. Of course, Bosworth's contributions of materials selection, grand architectural design, and especially the great dome, cannot go unappreciated as equally valuable contributions to the success of the main academic buildings at MIT.

CHAPTER 5

MASTER PLANS OF MIT

MIT has never suffered the pitfalls of other institutions through the practice of erecting the campus one building at a time with little or no regard for the past, the aesthetic whole, or the future progress of the institution. Since the conception of the original academic buildings in Cambridge, MIT has managed to develop and maintain a strong sense of direction and coherence in its master plans. The formal, all-encompassing campus plans of MIT are referred to as master plans.

Master plans include not only building design and specification information, but detailed information regarding the scope of future development, goals of the institution regarding size, services, and intent, plans for pedestrian and vehicular circulation, plans for open space and parking, plans for street and transportation interfaces, and service and utility recommendations as well.

1916 Master Plan

The original master plan for MIT, may have been officially created by the architect, William Welles Bosworth, but the basic criteria of the main academic buildings were established by Freeman. Freeman's main concerns, as mentioned earlier, were cost, efficiency, and adaptability. He recognized the need to design efficiently because of the limited amount of available funds. He further developed this idea of efficient building design into the need for adaptable buildings. Although he realized he could not predict

the changes that the Institute would undergo, he did have the advantage of the knowledge of the history of the Institute in the Back Bay to know that change was inevitable. Freeman addressed this problem of adaptability by designing flexible unit sections, which not only could be constructed less expensively because they were repeated over and over, but they were designed with no interior load-bearing partitions to maximize the adaptability of the interior space for use as laboratories, classrooms, offices or whatever other needs arose.

Freeman's goals for the campus buildings, as stated in 1910, were as follows:

1. An abundance of window light and a flood of controlled ventilation with tempered and filtered air.
2. Maximum economy in energy and time in circulation of students and instructors.
3. Maximum economy in cost of efficient service in heating, ventilating, janitor service, and general maintenance.
4. Maximum resistance to fire, decay, and wear.
5. Maximum economy in cost of building per square foot of useful floor space.
6. Recognition of the visual pleasure derived from the architectural details and proportions of the Greek Classical style.
7. A simple dominating mass with uniform cornice height which shall invite attention to the many thousands who pass the basin over the two great bridges.³⁶

³⁶MIT East Campus Master Plan, 1978, p. 7.

Subsequent MIT master plans expanded and refined these goals. One of the main goals of recent MIT Master Plans (1978 and 1989), is to establish continuity with the historic system and the City of Cambridge while providing a campus design which is consistent with the principles of campus planning.

1978 Master Plan

The 1978 East Campus Master Plan was a long term plan which projected the development of the East campus over a fifteen year period. There was a unique challenge in the development of this plan because of the necessity to integrate the East campus with the main campus so the basic Institutional objective of interdisciplinary communication could be achieved. The 1978 plan was a “development strategy to guide growth and change”.³⁷ The planners describe the concept of the East campus development this way:

“This framework derives in large measure from the basic pattern of MIT’s historic building system, with its roots in the 1916 Main Campus-- linear, interconnected, disciplined, a sequence of highly practical work spaces, yet composed to reflect MIT’s great intellectual idealism and social purpose. ...That Bold plan of interconnected buildings, with its many additions, has supported a long period of relatively stable growth and

³⁷ibid.

established an intensive environment of scientific interchange which has done so much to give MIT its particular strength and discipline. ...The broad conceptual goal of this plan is twofold: to establish continuity with this historic system, and at the same time continuity with the City of Cambridge along Main Street's complex edge".³⁸

The 1978 Master Plan was developed for the expansion into the East campus primarily for the Health Sciences/Health Services Complex. The fundamental goals, as established by the Planning department and its consultants are listed below:

1. Interconnected Building System

Provide maximum interaction between departmental and functional units and Institute facilities, through a network of primary and secondary corridors and vertical connections.

2. Flexible Growth System

Accommodate change and department regrouping via a modular building system with the necessary flexibility that will also respond to phasing and land acquisition.

3. Pedestrian Circulation Links

- a. Extend MIT system and Main Campus Corridors, with links to subway/Kendall Square, Sloan School, and Eastgate.
- b. Create a sense of place.

³⁸ibid.

- c. Give clarity, direction, and provide perceptible zones of transition.
 - d. Create clear definition of the outer boundaries of MIT campus, while at the same time provide clear access from the outside.
4. Systems of Open Spaces
- a. Relate to existing sequences and character of MIT open spaces.
 - b. Provide comfort, relaxation, and change of pace.
 - c. Provide views (sense of vista: dome, clock, tower, river,...), orientation (to define primary access points), perspective, light (allow penetration of sunlight), and shadow.
 - d. Use landscaping to screen, shade, create wind barriers, shield service lanes, and facilitate maintenance.
 - e. Promote happenings, allow a variety of activities (identify areas of special opportunity for Art).
5. Adjacent Plans and Land Uses
- a. Locate the Health Sciences/Health Services Complex in such a way that:
 - 1. When completed they are representative of the intent of the entire Master Plan.
 - 2. Create continuity with existing campus.
 - 3. Allow construction start in 1979.
 - b. Locate the subway headhouses so that they consolidate the main north-south access from Main Street to the central corridor.

- c. Set up traffic system to reduce the activity on the roads surrounding the East Campus (Ames, Amherst, Wadsworth) and to facilitate service and maintenance.
 - d. Create physical connections to Sloan and across (or under) Ames.
6. Infra Structure/Traffic/Services
- a. Phasing of utility network.
 - b. Permit easy and economical distribution system to fit MIT goals.
 - c. Provide for diversion of regional traffic.
 - d. Fit into existing permanent utilities structures.

The 1978 plan was a concerted effort to reemphasize the goals of the original buildings in hopes of repeating their success:

“ To the public view and to its own academic community, MIT’s campus is symbolic of the scientific and technological age that dominates the 20th century. Immensely adaptable, the old campus has taken on the mantle of a continuous interconnected entity. The planning and structural bay chosen by Bosworth has adapted to shifts in use and purpose as they have been altered through the years. ...The result has been a physical environment that encourages interdisciplinary interaction between staff and student. Believing that physical proximity enhances the potential for creativity and

intimate exchange between department and disciplines, MIT planners have always sought to translate this ideal into reality. The philosophy of overlapping department locations, of designed mixed-use buildings and interconnected flexible spaces has largely continued to this day. ...MIT's Departments and their offices are distributed throughout the Institute as a matter of stated policy, to encourage the cross fertilization of disciplines and facilitate their interaction. ...The Design Guidelines describe these influences as accessibility, connectivity, a sense of place, comfort, flexibility, changeability, compatibility, and economy.”³⁹

In an effort to emulate the success of the original buildings, a detailed study was performed to develop a prototypical series of uses, spaces, circulation patterns, and quality which could be applied to the creation of new, methodically created, connective spaces. This was all determined from a study of the main campus. By categorizing and examining spaces all over the Institute, it was possible for the planners to construct prototype models according to their flexibility implications. This prototypical space was referred to as a “functional” or functioning unit”. This study resulted in the following development:

³⁹ibid.

“It was discovered that there was basically two kinds of prototype space: one was the laboratory-oriented science area; the other was the small group-oriented seminar, classroom-oriented office cluster. This does not include the specialized types of spaces such as major lecture halls, auditoria, and public spaces. ...This functional unit as it was referred to, was used to define, in architectural terms, such things as length of corridor, length of corridor before a pause was made for stairs or elevators, floor to ceiling heights, number of floors,...”⁴⁰

In a much more detailed and sophisticated way the Master Plan of 1978 was also a use-based plan similar to the original 1916 Master Plan. This idea of defining a “functional unit” was again examined in the subsequent Master Plan in 1989. Although the name was changed to a “flexible module”, the importance of the concept was reemphasized and implemented once again.

⁴⁰ibid.

1989 Master Plan

The MIT Planning Department continues to revise and refine the principles of campus planning at MIT. The 1989 MIT Main Campus Northeast Sector Master Plan expands and reemphasizes the importance of the following criteria: communications, accessibility, connectivity, sense of place, flexibility, comfort, compatibility, and economy. These criteria make up the principles of MIT campus planning today and are discussed below:

Communication: to provide settings that facilitate communication and promote interaction among all segments of the MIT community.

Accessibility: to ensure accessibility

- within the Institute to academic and support services, people and programs;
- from the Institute to community services; and
- from the community to MIT's unique people, skills and technology.

Connectivity: to enhance and further develop the existing indoor and outdoor connections between West, Main, East, and Sloan campuses which intersect or terminate at principle city arteries.

Flexibility/Changeability: to design and develop buildings, circulation, service/utility systems, and open space to adapt to the needs of an evolving

academic environment and to be responsive to change. To this end, they must accommodate changing users and program requirements economically and with minimal disruption of academic work.

Sense of Place: to establish an environment that is organized and comprehensible, where the arrangement of physical elements is memorable, has aesthetic order, and contains identifiable, visually satisfying places.

Comfort: to provide a safe and pleasant environment in which to live, work, learn, and play. The ambience must be many things to many people and reflect in its variety the diversity of users and functions to be accommodated.

Compatibility: to employ components whose scale and materials are compatible with those already established. Also, to preserve the continuity of open space and buildings to ensure the orderly integration of additions to the existing campus and Cambridge community.

Economy: to plan and design capital improvements to be cost effective over their full life cycles and to conserve the Institute's resources, while balancing

high design/construction quality standards with economic restraints.⁴¹

The recurring theme as an objective of successful campus planning is the “informal interaction among all members of the MIT community, this interaction is fostered by public spaces, and meeting places of appropriate design at building entrances, lobbies, corridors, open stairs, and public lounges.”⁴²

The building objectives defined in the 1989 MIT Master Plan Northeast Sector include:

1. Buildings will contain spaces which foster fruitful interaction.
2. Buildings will be connected with inside and outside pathways which help unite the campus.
3. Facilities will have the flexibility to accommodate a variety of future uses.
4. Open spaces will be hospitable and inviting.
5. Campus facilities are centrally administered so that space can be reorganized as disciplines and research efforts grow, merge, and change.⁴³

It is easy to see that continuity, refinement, and improvement of the planning process is a constant goal of the MIT Master Plans.

⁴¹MIT Main Campus Northeast Sector Master Plan, 1989.

⁴²ibid.

⁴³ibid.

Flexible Building Module

Freeman's original intent of adaptable buildings has grown into a conscious effort of the planning department to emulate the phenomenon by establishing a flexible building module concept. "The module defines the building width, floor spacing, structural bay, and service distribution, and provides for space allocation for a range of uses over time. ...flexible building modules are used in most MIT buildings, permitting economical and non-disruptive modification when space is reassigned as laboratory technologies change".⁴⁴ The development of this concept by Freeman and the continuing evaluation and improvement of the flexible building module concept allows MIT to meet and exceed its goals of efficient and effective flexible and adaptable academic facilities.

⁴⁴ibid.

PART III
COMPARATIVE ANALYSIS

CHAPTER 6

THE GREEN BUILDING

The Cecil H. and Ida F. Green Building, also known as Building number 54, is a dramatic departure from traditional MIT architecture. The building, which houses the Center for Earth and Planetary Sciences, is a twenty-one story tower which stands alone in the center of the main campus with no above ground or below ground connections to any other campus buildings. Although this building is dramatically different from all others on campus, many of the same planning criteria were used in its development and design. The similarities and differences of this building's design, as compared to the main academic buildings, will be used to illustrate the importance of adhering to the fundamental design features of flexible buildings.

The Earth Sciences have always been an important department at MIT. William Barton Rogers, the founder, was a geologist and geology has been a part of MIT's curriculum since the Institute opened in 1865. In the early 1950's Cecil Green, a 1923 graduate of the Department of Electrical Engineering and then President of Geophysical Services, Inc., an oil exploration company in Dallas, Texas, took a particular interest in the Geology Department at MIT. Green had spoken with the Electrical Engineering Department regarding hiring students for summer work or graduates for full time employment. The demand for electrical engineers was so great at the time that few, if any, were available for employment. Green

then inquired in the geology department regarding recruitment possibilities.

The ensuing meetings with the geology department resulted in the formation of the Student Cooperative Plan, which selected students to work as field geologists during the summer vacation. The plan was eventually opened to all universities. The Student Cooperative Plan, which operated from 1951 to 1967, is just one example of the educational programs, conferences and symposia that Mr. Green has organized over the years at MIT.

Mr. Green's greatest gift to MIT certainly has to be his generous donation for the construction of the Cecil and Ida Green Building, Center for Earth Sciences. The Green gift of \$2,527,500 was made in 1959 in the form of 30,000 shares of stock of Texas Instruments Incorporated. Mr. Green was a vice-president of Texas Instruments at the time. The intent of the gift was to "enable MIT to build a multi-story Center which will house the laboratories on its campus that are now actively exploring the physical environment. Geologists, chemists, physicists, meteorologists, and oceanographers will now be able to perform work side by side in a basic and applied scientific program which will have, I am certain, the greatest impact on our economy and society as a whole."⁴⁵ Mr. Green gave the following reasons for making the gift, "Within the all-encompassing field of science itself, the importance of the earth sciences has been increasing with almost explosive force. For our country to maintain leadership in these areas in competition with

⁴⁵Shrock, p. 143.

other nations, or even to keep abreast in the race to new knowledge, we believe it imperative that greater effort be devoted within these fields, and to center that effort where it can bear fruit most quickly.”⁴⁶

Immediately after the announcement of the gift, the process of selecting a site and planning the building was begun. The major considerations included the location of the building, the size and form of the building, who would design the building and who would build it. On May 4, 1959 a meeting was held of the Building Committee which consisted of:

- J. A. Stratton, President
- E. L. Cochrane, Special Advisor to Stratton
- J. J. Snyder, Treasurer
- P. Belluschi, Dean, School of Architecture and Planning
- G. R. Harrison, Dean, School of Science
- C. F. Floe, Adm. Vice Chancellor
- M. G. Kispert, Vice Chancellor
- P. A. Stoddard, Vice Treasurer
- F. Bitter, Assoc. Dean, School of Science
- C. M. Peterson, Director, Physical Plant
- M. D. Rivkin, Planning Office
- P. M. Morse, Chairman of the Faculty
- J. T. Rule, Dean of Students
- R. R. Shrock, Chmn. Department of Geology and Physics⁴⁷

⁴⁶ibid., p. 143.

⁴⁷ibid., p. 145.

The decisions made at this meeting, which were approved a few days later by the full Building Committee, included that the building was to be located between the Dorrance Building (see figure 9) and the parallel dormitories to the east, the height of the building was to be eight stories and one basement, there was to be a 3000 square foot auditorium, the building was to be air-conditioned, and the architect was to be I. M. Pei, class of '30, and O'neil Ford, of San Antonio, Texas, was to be a consultant.

The cost estimate of the building described above came in at approximately \$4,000,000 which was approximately \$1,500,000 higher than the original estimates. Upon learning of this cost increase, Mr Green, fearful that the auditorium or air-conditioning might have to be eliminated, agreed to pledge the additional construction funds and also pledged a special fund for maintenance and future alterations of the building.

The information gathering for the planning of the Green Building was broken down into three parts. The first part was the financial planning, the second part, handled by the Director of Physical Plant, was the coordination of all outside facilities such as sewers, electrical service, water, power, telephone, loading and delivery and all fixed equipment in the building. The third part, which was prepared by Professor Shrock, described the program of activities in the building, the circulation and flow, preliminary floor layouts, required furniture and equipment, etc (see figure 10).⁴⁸

⁴⁸ibid. p. 147.

After Pei received the three volumes of building program information, the envisioned plan for the building changed. Pei decided to dramatically change the building by essentially cutting it in half, stacking the additional floors on top of one another, so it was a 20 story tower instead of an eight story building (see figure 11). An article in *Architectural Forum* summed up Pei's intent this way:

“Pei's notion was to add his building to that area in such a way as to pull all the others together into some kind of organized composition without trying to supplant the dominant court and dome. The device was a tower of minimum floor area so placed as to bring the space around it into focus -- like a flagpole in a public square. Once the idea of a tower was accepted,..., Pei and his associates studied the program for the building. What seemed to be required was a large single bay floor, strictly organized on a 5-foot module, which could be laid out variously for offices, laboratories, classrooms, or lecture rooms and changed as the future might require”.⁴⁹

This design had several perceived advantages. First, it minimized the ground area it used so it maximized the space left over for expansion and construction of other buildings. Second, it

⁴⁹“A Tower Built Like a Bridge”, *Architectural Forum*, v.113, Aug. 1960.

offered a roof deck which could be used as a meteorology laboratory. Finally, it fit well into the long term plans for the development of the Eastman Court area. Although the location of this stand-alone tower was contrary to MIT's long-standing tradition of interconnected buildings, Pei's argument must have been very persuasive. Pei argued: "From an aesthetic point of view, let the tower break free from the surrounding buildings and rise with surrounding spaces beautified".

The architectural community was quick to comment on Pei's design. The quote by David Guise summarizes the main successes and failures of the building:

"Locating the cores at the ends of the building instead of the more traditional center, created a number of advantages in addition to providing the uninterrupted, open floor space. Each of the two required stairs is located in an opposite core. This solution provides maximum exiting safety because it eliminates all dead-end spaces. All the elevators are placed in one core, and the washrooms at the other, providing a clarity of circulation. Unfortunately, the amount of vertical shaft space provided within the cores turned out to be woefully inadequate for the high demands and *constant layout changes that user needs impose on a university research laboratory* (italics mine). ...Despite the problem the university has had with the lack of adequate mechanical shaft space, as well as the

terrible wind-tunnel effects in the portico entrance area, which eventually led to the redesign of the entrance, the building makes a handsome contribution to the campus. One could wish for more honesty in the handling of the two similarly scaled horizontal bands at the top and bottom, but must admire the handsome use of texture and subtle reveal to create a structure that will probably age more gracefully than most other poured concrete edifices”.⁵⁰

⁵⁰Guise, p. 207.

CHAPTER 7

COMPARATIVE ANALYSIS

The main academic buildings at MIT have proven immensely adaptable to changes in use through the years. This is attributable to the structural bay size selected by Freeman and Bosworth. The ease of circulation and the effective interconnectivity of the buildings is also attributable to features designed into the original structures.

Freeman extensively studied the optimum bay size with respect to natural light, fenestration, and flexibility. Freeman and Bosworth also incorporated other aspects in the design that would provide ease of expansion. For instance, the first floor of Building 3 was two stories high until the 1960's when the second floor was added. The addition of the second floor was relatively easy because Freeman and Bosworth had incorporated structural supports midway up columns to support the anticipated addition of a second floor.

An comparative study of structural bay size and its effect on useable space offers some insight into the efficiency of the main academic buildings compared to the Green Building.

Building Efficiency Comparison⁵¹

Building Number/ Year Occupied	# of Floors/ #of Basemt. Floors	Assignable Square Footage/ Useable Square Footage = Efficiency	Structural Bay Size*
Building 1 1916	3 + 1	78397/105706 = 74.17%	13'6" X 20'6" 13'6" X 25'0"
Building 2 1916	3 + 1	74974/105710 = 70.92%	13'6" X 20'6" 13'6" X 25'0"
Building 3 1916	4 + 1	108510/148861 = 72.89%	13'6" X 20'6" 13'6" X 25'0"
Building 4 1916	4 + 1	105459/146667 = 71.90%	13'6" X 20'6" 13'6" X 25'0"
Total**: Main Academic Buildings		367,340/506,944 = 72.46%	
Building 54 1964	21 + 1	69,068/114027 = 60.57%	8'8" X 15'9" 8'8" X 24'9"

* Structural bay size for buildings 1 through 4 is approximate.

** Building number 10 is not included because it has always been intended to house the library and not to be a "flexible" space.

It is clear that building 54 is not as efficient as the original academic buildings on campus. The efficiency calculated in the

⁵¹Building Data: Academic Facilities, MIT Office of Facilities Management Systems, 1987

table is actually higher than is believed to be true by the MIT Planning Department. Pei's decision to make building 54 a narrow tower is what reduces the efficiency of the building area. The taller the building, the more area is required in the service shafts for the services such as elevators and mechanical and electrical systems. This then reduces the total amount of assignable square footage.

Although Pei perceived this tower design to be aesthetically advantageous, it can be seen as a disadvantage to circulation, flow, student-faculty interaction and generally sets the Earth and Planetary Sciences students apart from the rest of the departments on campus. The main institutional and academic goal of interaction among faculty and students of all disciplines suffers greatly in Pei's design.

Pei's building is a success, though, at satisfying the building design goal of a flexible floor layout. Each floor is basically uninterrupted by structural columns which allows complete flexibility of classrooms, laboratories, offices and other facilities. Pei accomplished this by dividing up the core of the building into two parts, one at either end of the building. This is done at a sacrifice of building efficiency, that is the percentage of useable space compared to the net square footage of the building as was discussed above. The building height limits circulation, as verticality tends to discourage people from travelling between floors. The relatively small foot print of the floors also means that fewer students and faculty come into contact with one another on a daily basis. Overall, the Green Building accomplishes what Pei perceived as the program. However, some of the critical components

of MIT's main institutional and academic goals, such as interconnectivity of buildings to promote communication, were superseded by the wishes of the architect to house the department in a tower.

Pei's building also has proven to be difficult to modify. It is true that the interior partitions are non-load bearing and that the interior spaces can be reconfigured in many ways, but the limited size of the two service cores has proven inadequate to handle the changing needs of a research facility. For instance, additional electrical and communication service for computers, world processors, and laboratory and office equipment has been required. In addition, these new services require additional cooling capacity. The demands for cooling have increased greatly with the introduction of computer rooms and new electronic office and laboratory equipment. Not only is the available shaft space limited to accommodate these new requirements but it is significantly more difficult to run these services twenty stories than the usual three or four of the main academic buildings. The main academic buildings have many vertical risers which can accommodate new services. There are choices of stacking these facilities or separating them to allow adequate space. The high ceilings of the main academic buildings provide ample space to run additional or replacement conduits as the need arises. The lower ceiling heights in the Green Building offer a limited amount of space to run additional systems as new needs arise.

Pei's design, although considered architecturally successful, does not meet the goals of an easily adaptable institutional building.

The program, as developed by the Planning Department and the Geology and Earth Sciences Faculty, was not faithfully interpreted by the architect. The recommended floor footprints, which were virtually cut in half, resulted in a building which was too tall and narrow to adequately adapt to the service and utility changes which are demanded by a university research laboratory.

PART IV

OTHER RESEARCH AND CONCLUSION

CHAPTER 8

OTHER RESEARCH ON FLEXIBLE INSTITUTIONAL BUILDINGS

There has been other research done on the characteristics of flexible institutional buildings. Thomas Allen, a Professor at the Sloan School at MIT, has done extensive research on architecture's influence on the success of R & D facilities. Roberto Pietroforte, a doctoral candidate at MIT, has done research on the academic buildings at MIT to try to determine quantifiable indicators of building flexibility and adaptability. A summary of their research is given below.

Research Facility Architecture and its Effect on Communication

Thomas J. Allen of the Sloan School of Management at MIT has written extensively on the subject of how architecture can influence communication and performance in a research facility. He has studied and proven not only the importance of communication among R & D staff, but also how the physical design and relative location of the buildings strongly affect the facility's performance.⁵²

Allen's theory is a simple one, "If communication is such an important determinant of R & D performance (Allen, 1970), and if it, in turn is strongly influenced by physical layout, then it follows directly that communication among inhabitants should be an important criterion in the physical design of a research laboratory.

⁵²Allen, No. 692-74.

In spite of the self-evident nature of this conclusion, one does not have to visit very many R & D establishments before concluding that it is observed in the breach if at all". Allen goes on to offer two reasons for such apparent neglect for the incorporation of communication considerations in research facility architecture. The first is that convincing empirical research had only been developed recently and that most architects are unaware of the important link between communication and building layout. The second reason is that, until Allen's study in 1974, there had been no research which targeted the relationship between physical layout and communication specifically in research laboratories.

Allen had previously proven the very strong influence that good communication had on R & D performance. For example, in his 1964 study, Allen found that proposal teams which consulted more with colleagues produced higher quality proposals. In addition, in 1966 and 1970 studies, Allen found that "for matched pairs of identical projects, engineers who obtained ideas from organizational colleagues, or who consulted more within their organizations, during the project, produced better technical solutions". There were studies by other researchers which supported Allen's findings (Pelz and Andrews (1966), Baker (1967), Hagstrom (1965), and Shilling and Bernard (1964)).

Allen's theory of improving intra-organization communication through improved building design and architecture is based on a study of human interaction and relative location. Allen studied seven R & D laboratories. The facilities ranged in size from 48 to 170 professionals, and included two university laboratories, two

laboratories in the aerospace industry, one in the chemical industry, one in the computer industry, and one government agricultural research laboratory. Not all research laboratories were housed in the same buildings. Communication was measured by questionnaire which inquired about the frequency of communication with specified colleagues (at known relative distances) regarding only technical and scientific matters. The study was specifically restricted to technical and scientific matters because other studies have shown that friendship and proximity also affect frequency of communication but do not necessarily contribute to performance.

Allen's results showed that, as one would suspect, that frequency of communication decreases with the distance between professionals (desk to desk distance). What is particularly interesting is that "it is only within the first 25 to 30 meters that separation has any real effect on the probability of communication".⁵³ Allen also examined intra-group communication, i.e. co-workers with similar backgrounds and areas of research, and found that there is only a slightly greater probability that an individual will travel a given distance to talk to someone else in his group.

Allen uses these results to offer suggestions on how to improve R & D performance through improved architectural design. First of all he criticizes the traditional layout of "arraying offices in a linear fashion along a hallway [which] maximizes the separation distance between occupants of the offices, and is hardly the best

⁵³ibid., p. 8.

way to promote communication". Allen suggests using a circular or square configuration to minimize the distance between employees but realizes that it is not always feasible and, furthermore, believes that the extremes of building shapes, H's, N's, Z's, and W's, is going too far. One of the major flaws that Allen observes in traditional building design is a result of trying to give everyone an outside exposure. Although a nice view is desirable, Allen suggests locating common areas such as corridors, meeting rooms, libraries, and break areas along the windows, instead of just the executive offices, so everyone has equal access to an outside view. Allen further states that "the less differentiation there is in the desirability of office locations, the greater the flexibility possible to making office assignments. One thing is certain, if the head of the organization wants to keep in close touch with what is going on in his organization, he must resist the temptation to locate his office in the corner with the best view. The center of the building is the place for him. This will minimize average separation between his office and the location of the groups reporting to him. Otherwise, he is going to be farther from some groups than others with a corresponding degradation in communication".⁵⁴

Allen also examined vertical separation and the effect of multi-story buildings on intra-organization communication. It is not only the actual desk-to-desk distance which affects communication in multi-story buildings, but also the location, accessibility, and visual contact of stairs and elevators.

⁵⁴ibid., p. 13.

Accessibility refers to things such as, whether the stairs are open or protected by a fire door, and visual contact refers to the ability for people to openly view the other floors such as in a mezzanine situation. Surprisingly what Allen determined is that people are just as reluctant to use an elevator as they are to climb stairs. Of course, this holds true for one and maybe two stories, but people are obviously more reluctant to climb ten stories of stairs than to travel ten stories by elevator.

Allen does not use this information to suggest that single story buildings are desirable in all cases. He recognizes that land values are an important consideration in determining building configuration and that at some point a single story structure would get so large that the average separation between offices would exceed that of a multi-story building.

Allen's study compared the mean separation distance between people located on one floor and those located on different floors for several size buildings. His results concluded, after making some adjustments for the effects of staircases and elevators, that the "most important conclusion from this analysis is that, for communication purposes, a research manager would want to limit his laboratory to a single square building, as long as the required floor-space is less than 10,000 square meters. Above that area, the building should have at least three floors, and elevators should be used". This study shows that circulation within a research facility is greatly impacted by the use of stairs, and that a two story

building, regardless of the size of the floor plate, cannot overcome that impact.⁵⁵

Relevance to Buildings at MIT

Professor Allen's research obviously came years after the design and construction of the original buildings at MIT. In 1916 there were other considerations which outweighed those of improved communication today. For instance, it would have been ridiculous at that time to locate all the corridors along the windows because the windows were needed for the more basic needs of light and ventilation. Freeman, though, did recognize the importance of communication among faculty and students and the need for common areas and easy circulation patterns to promote this communication. He also incorporated this idea of shortening circulation time between classes by his grand idea of housing all the facilities in one building. Although Freeman's ideas were not illustrated by quantitative research the same concerns and considerations were taken into account when he studied the most effective configuration for academic facilities.

The Green Building illustrates an example of communication and interaction limitations with respect to multi-story buildings. Although the floor footprints of the Green Building are relatively small, the vertical separation in the building discourages communication among colleagues. This causes particular problems

⁵⁵ibid., p. 19.

when similar research is being carried out on floors which are more than two stories apart.

The main academic buildings at MIT, on the other hand, do not suffer the same problems of isolation due to vertical separation as in the Green Building. Although the buildings are three or four stories in height and have a quite large footprints, the frequency of stairwells, the wide open corridors and the open, communal spaces, such as Lobby 7 and Lobby 10, overcome the problems of vertical separation by increasing the frequency of communication and interaction among users.

Space Growth and Change in Academic Buildings

Roberto Pietroforte, a doctoral candidate at MIT, has studied general patterns of space growth and change in academic research buildings on the MIT campus to determine some “meaningful dimensions and quantifiable indicators of flexibility and adaptability of the physical environment”.⁵⁶ Pietroforte points out that flexibility and adaptability are often listed as criteria in building planning but translating these dimensions into physical space is difficult because of the unpredictability of future needs and the lack of specific understanding on the relationship between time and space. Implementing the goal of “generic flexibility” in buildings often results in “high initial premium costs and uncertain future benefits”.⁵⁷ Pietroforte studies historical data relating to

⁵⁶Pietroforte, p. 1.

⁵⁷ibid., p. 1.

spatial behavior to determine those aspects which have a bearing on the specific flexibility and adaptability requirements of a building.

The change of use of an academic building at MIT is often directly related to the growth or change of the departments they host. Pietroforte's study examined historical data relating to the allocation of space to departments and the use of that space for functions such as classrooms, laboratories, offices, and ancillary space. He determined that the functional parts of the Schools (he studied the Schools of Engineering and Science) did not grow at the same rate. He found that from 1967 to 1987 the allocation of the space had disproportionately increased for ancillary and office space and that the space used as laboratories had decreased significantly. Pietroforte offers several reasons for this change of space such as overall growth in administrative staff, the increasing use of computers and subsequently the increase of computer rooms (which tend to be large due to economies of scale), and the change in laboratory research activity to less space-intensive applications such as simulation techniques.

Pietroforte also studied patterns in departmental growth and change. These patterns of growth show that the departments now are characterized by space allocation fragmentation, with more and smaller departments than in the past. For instance, the Schools of Engineering and Science, "which have represented the historical backbone of MIT education and research programs, are supported by 24 departmental centers and laboratories of more recent

formation".⁵⁸ The research generally shows that as a part of a department grows it tends to split off into its own distinct unit and its space is no longer allocated to the original department from which it developed. Perhaps one of the most interesting conclusions of Pietroforte's research is, as he states:

"In their growth, departments often use existing spaces not designed according to the actual needs of activities. Different amounts of space are allocated to the same functional activity, e. g., office functions, with consequent waste. The majority of departmental activities, however, can be housed in a limited range of space sizes. This suggests the possibility of conceiving new 'indeterminate' or temporary buildings whose room dimensions act as the common denominator of the space required by various routines. The issue of adaptability and flexibility has several distinct implications. On the campus level [it] is intended as capability of expansion of and connectivity between buildings, as careful matching of space characteristics to activities requirements in order to lengthen the functional life of the existing buildings and as quick relocation of changing departmental activities. On the level of the single building, physical considerations such as geometric configuration of

⁵⁸ibid., p. 4.

structures, height of floors, relationship between service systems and space and capability of utility systems, are more prevalent”.⁵⁹

Pietroforte’s research supports the MIT Planning Department’s realization of the importance of constructing flexible and adaptable institutional space. His findings strongly support the use of “flexible building modules” which offer readily available, adaptable space for expanding newly developing and fragmenting academic and research departments.

⁵⁹ibid., p. 7.

CHAPTER 9

CONCLUSION

Characteristics of Flexible Buildings

The only thing that an institutional planning department can predict with certainty is the inevitability of change. The future requirements of an academic institution are uncertain and unpredictable and a campus must be designed to meet the future needs regardless of the changing nature of the institution. The change can occur in the academic or research programs which are directly affected by changing technological and societal needs. Academic institutions must also adapt to the changing and shifting population and student body constitution. The uncertain level and availability of capital funding is an important consideration when determining the adaptive nature of an academic facility.

Due to the changing nature of academic institutions, flexibility and adaptability are the most vital characteristics of academic institutional buildings. The way to provide this flexibility is to construct the building with non-load bearing interior partitions, to design large, open structural bays, and provide sufficient and accessible space for new and changing mechanical, electrical, communication, and other building services. Other critical elements include providing open corridors, stairways, and circulation spaces with adequate elevator service and frequent communal areas, providing large amounts of light with a pattern of windows which supports the flexible building module size, and finally constructing

interior and exterior architectural features of high quality and durability and of enduring aesthetically pleasing designs which will give a timeless quality to the campus architecture.

The two cases examined in this paper illustrate the importance of not only the design features mentioned above, but the design process as well. To achieve effective institutional buildings, it is important to design on a collaborative basis. The importance of this collaborative effort is best illustrated by the success of Bosworth and Freeman on the main academic buildings compared to Pei's design of the Green Building, which compromised the input of the building committee by the architect's insistence on a tower. The members of a collaborative design development effort should include those responsible for and those impacted by the building. This group should include the architect and engineer, members of the planning department, the faculty of the influenced departments (who are essential to developing a thorough and insightful building program), and the facilities maintenance department which can offer invaluable information on the availability of services and a historical perspective on building maintenance and renovation.

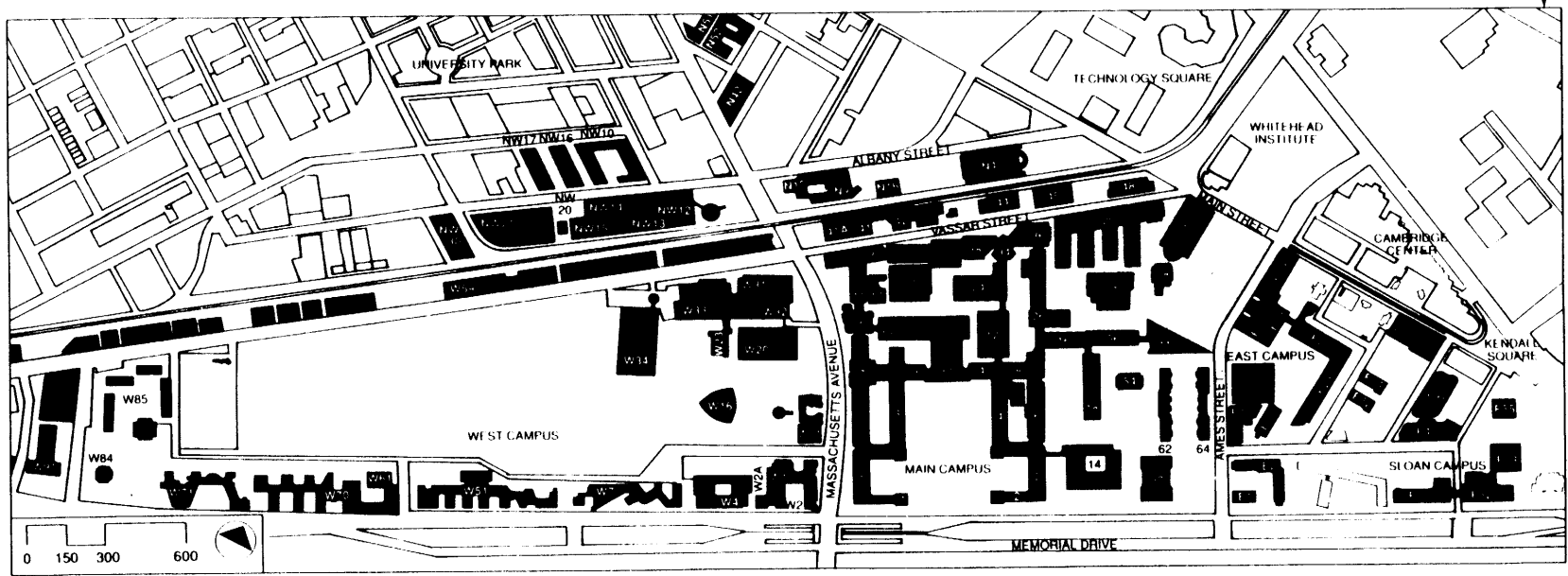
The importance of a detailed campus plan in meeting the changing needs of an academic institution cannot be overestimated. This plan should include the goals and objectives of the institution, provide for functional and adaptable buildings to meet the changing academic and research requirements, offer a method of translating the academic program into physical facilities, and do all this in an aesthetically pleasing architectural style. A campus plan should

incorporate all the knowledge of the past and offer a viable path to meet the changing needs of the future.

PART V
APPENDICES

APPENDIX A

PHOTOGRAPHS, MAPS, AND ILLUSTRATIONS



The MIT campus and its surroundings.

Figure 1

Mid-19th century rendering of Ramée's plan
6A
Contemporary air-view of Union College
Before construction of Schaffer Library.

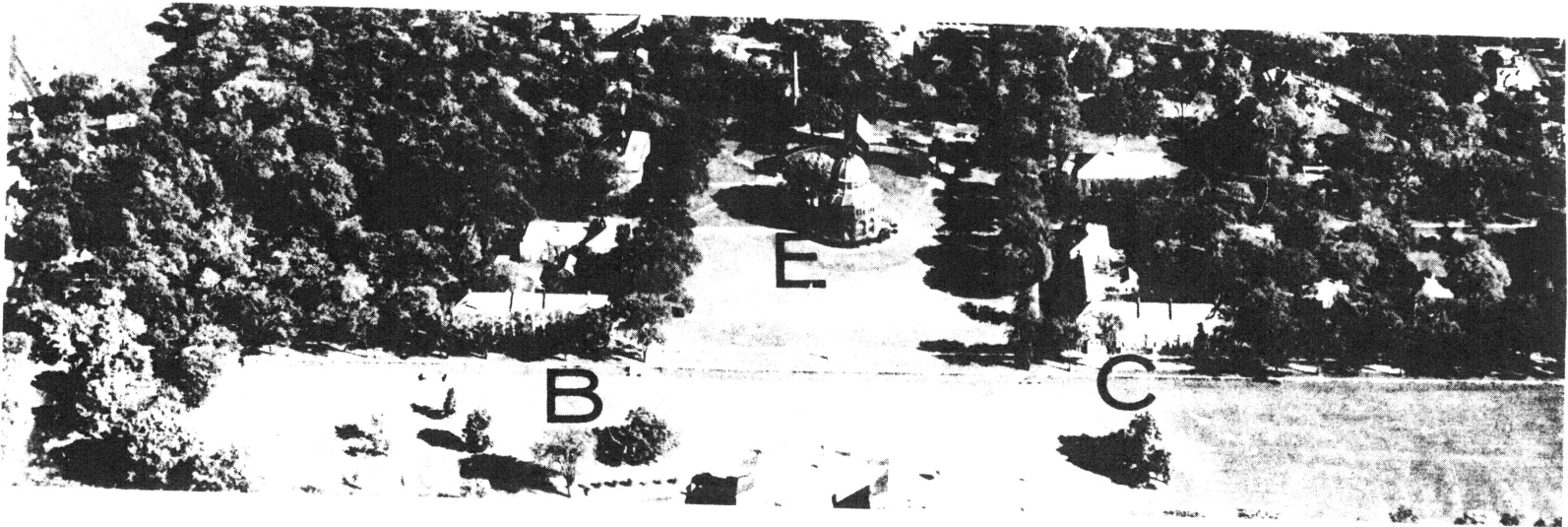
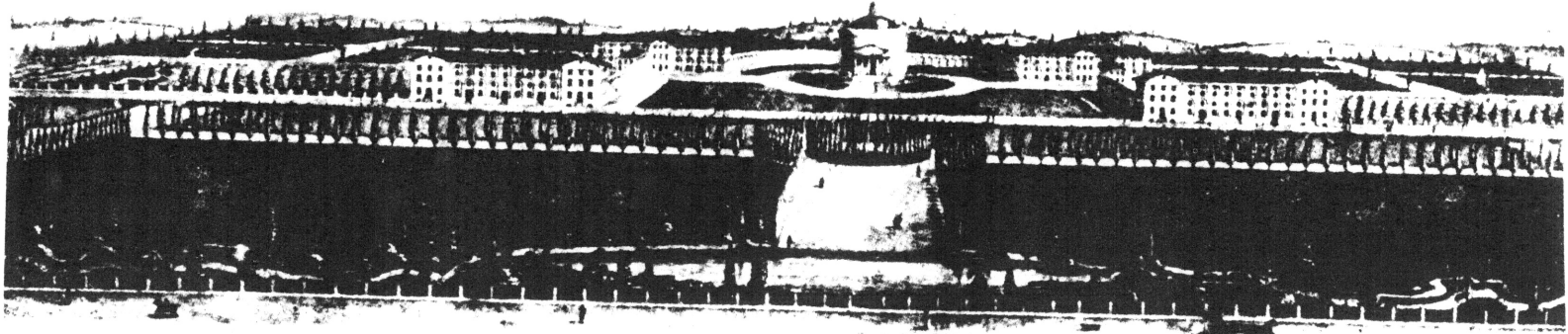
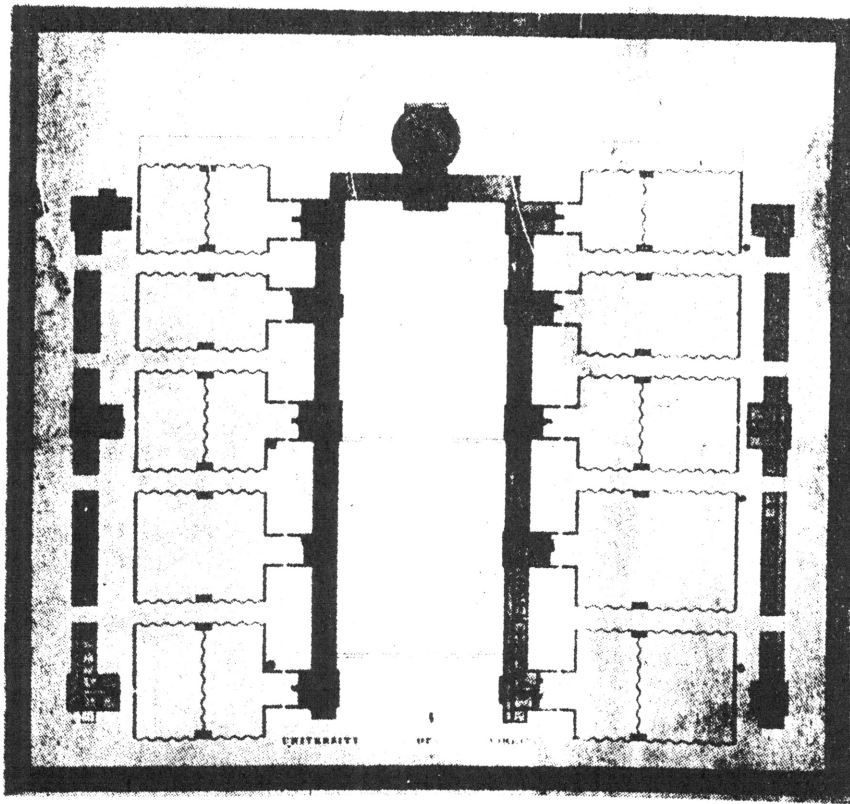


Figure 2



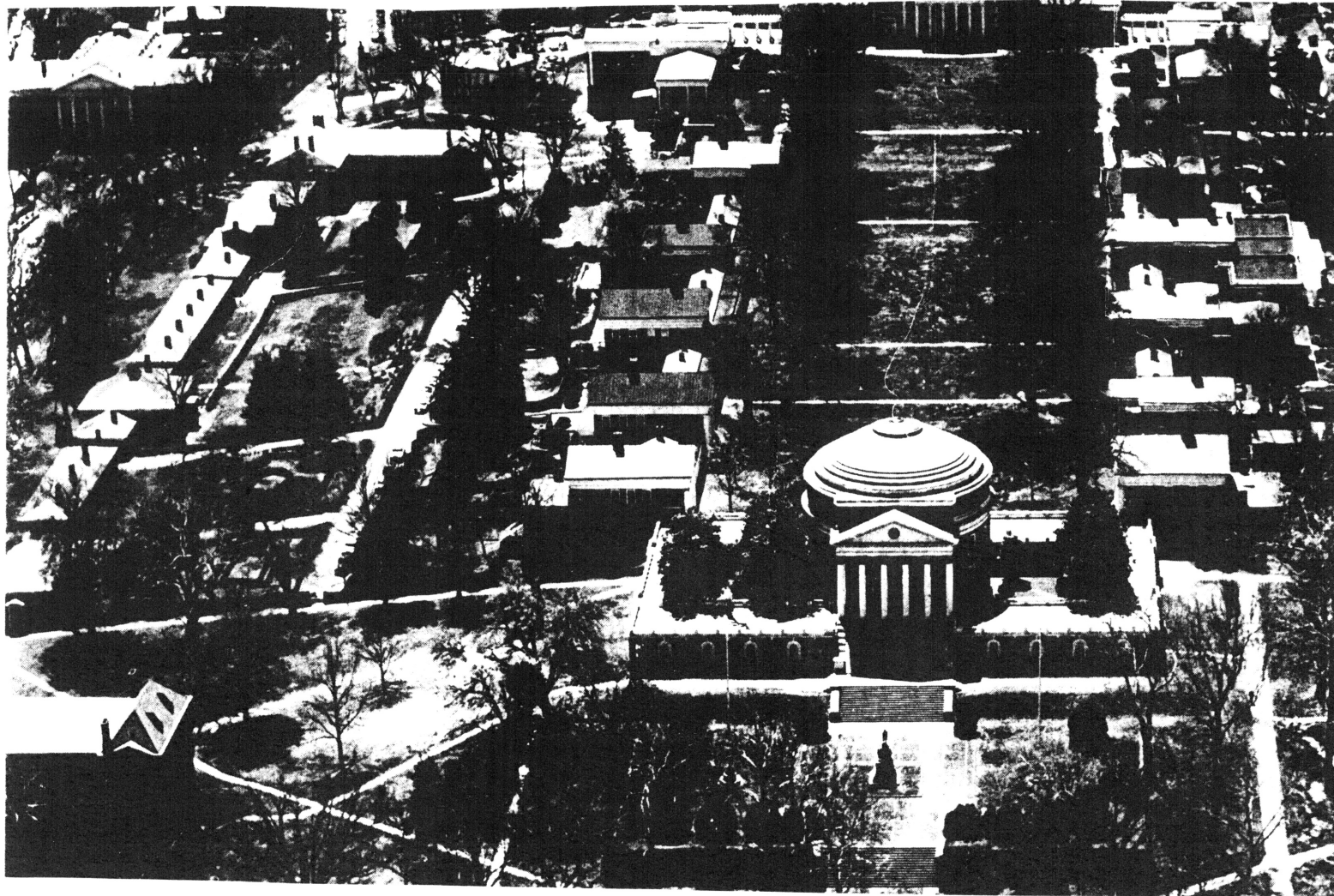
10B, C

The Maverick drawing (1825)

Showing the disposition of buildings in accordance with Jefferson's final scheme. Fire, minor renovations and alterations, plus Stanford White's buildings which terminate the end of the lawns have not compromised the original design, as seen in the contemporary air-view to the right.

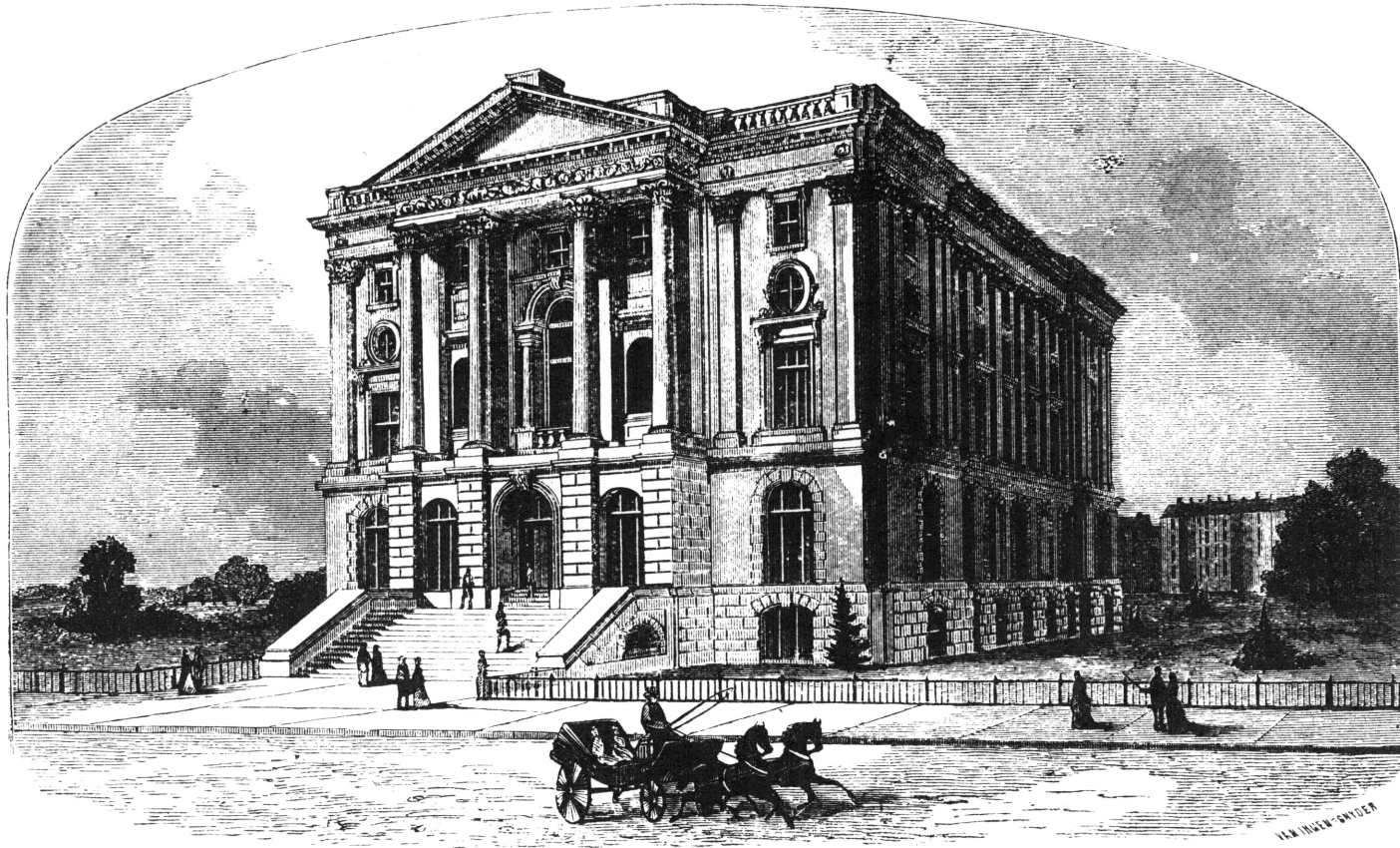
AIR PHOTO: RALPH THOMSON
DRAWING: INFORMATION SERVICE OF VIRGINIA

Figure 3



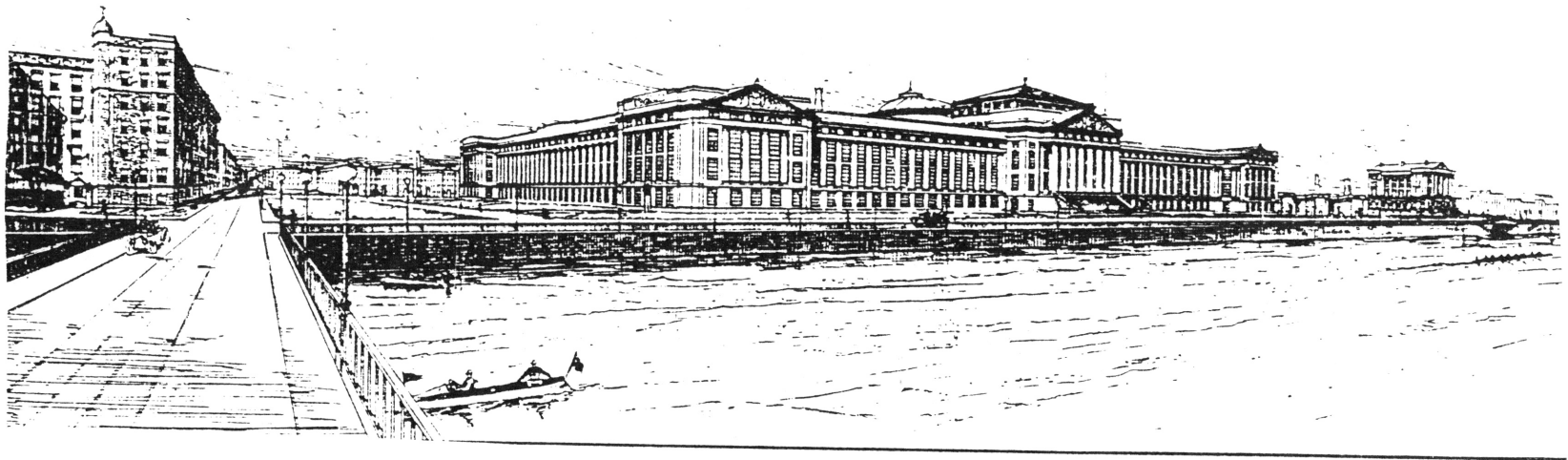
University of Virginia

Figure 4



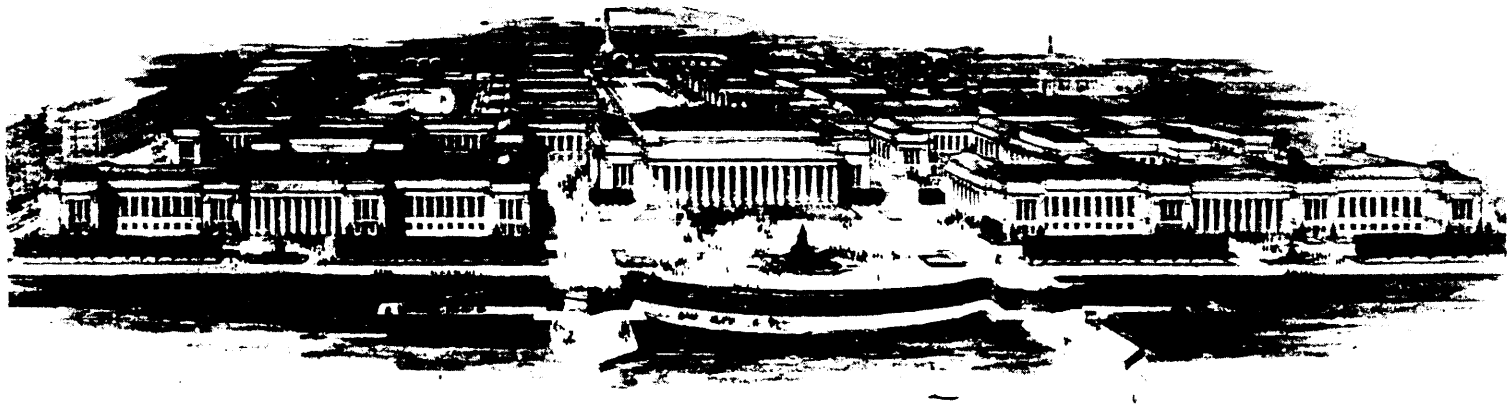
Occupied in 1866, and named in 1883 for William Barton Rogers, the Rogers Building was the Institute's center for sixty years.

Figure 5



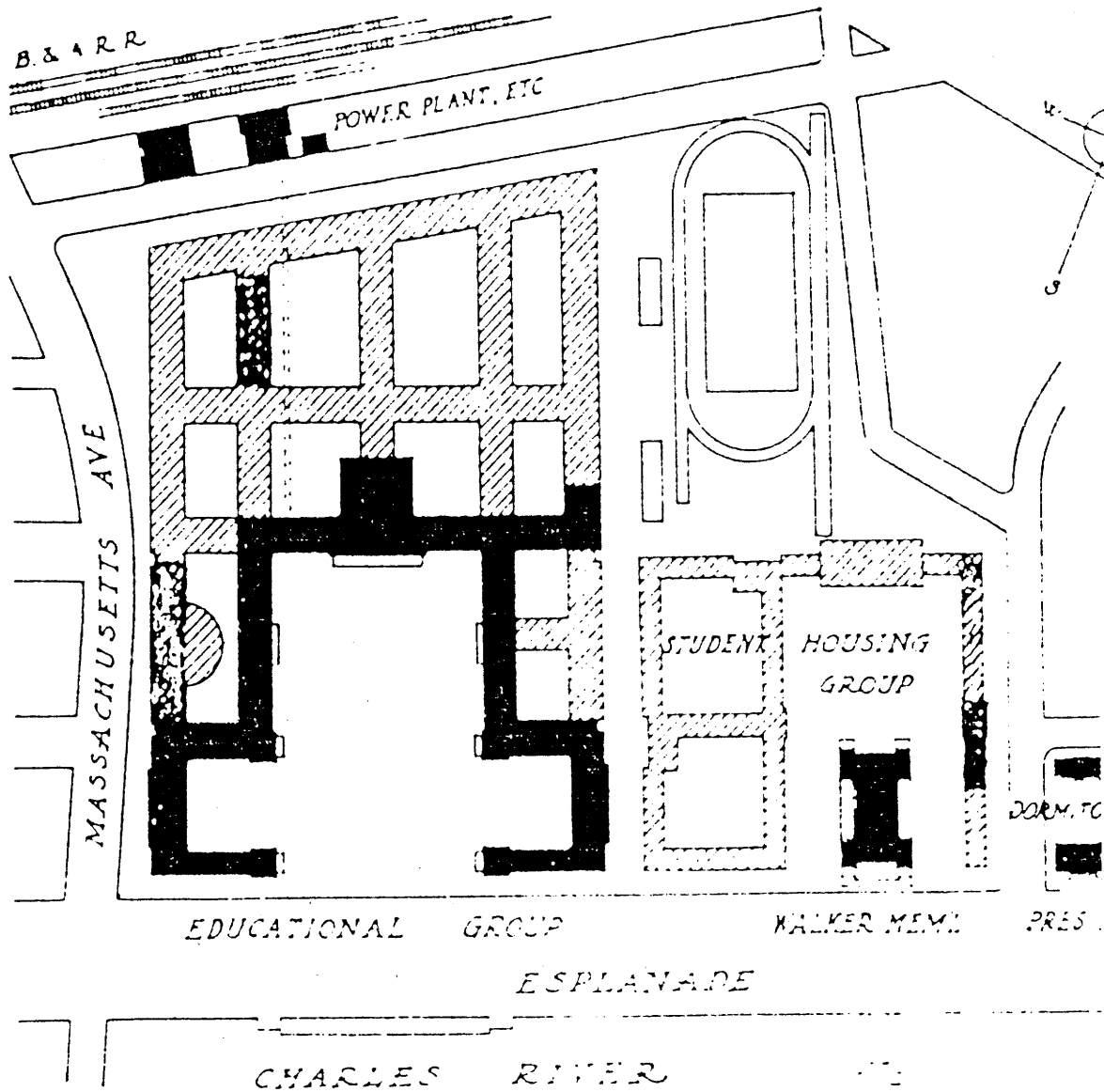
Freeman's Design

Figure 6



Despardelles' Design

Figure 7



Plot Plan of Complete Group

Bosworth's Plan

Figure 8

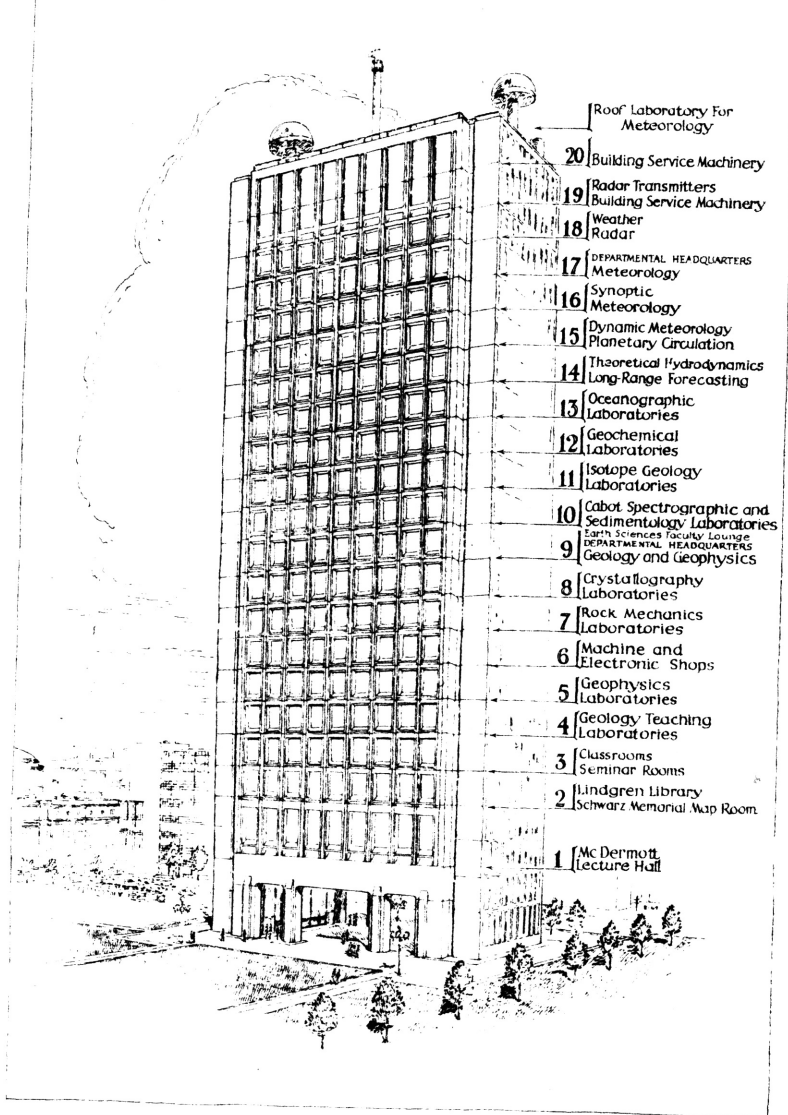


Aerial view of the M.I.T. campus, looking west, with site of the proposed Green Building indicated by X at the northeast corner of Eastman Court, directly northwest of the "Parallels" dormitories, in lower left-hand area.

(M.I.T. Historical Collections)

Figure 9

CECIL AND IDA GREEN BUILDING
 CENTER FOR EARTH SCIENCES
 MASSACHUSETTS INSTITUTE OF TECHNOLOGY



The above Sketch was kindly prepared by Percy Lund to indicate the facilities and activities assigned to the different floors of the Green Building at the time it was being completed and occupied in early 1964. Since then, however, many alterations have had to be made as faculty and staff, and instruction and research, have changed. Numerous of the floors occupied by Geology and Geophysics are shown on preceding page 130.

Figure 11

APPENDIX B

TABLES

Growth of MIT Population⁶⁰

Year	Students (U)	Students (G)	Total	Faculty	Student: Faculty Ratio
1900	*	*	1300	56	23:1
1916	*	*	1957	*	*
1935	*	*	2540	*	*
1945	1160	378	1538	582	2.6:1
1955	3656	1992	5648	1639	3.4:1
1965	3755	3653	7408	905	8.2:1
1975	4433	4049	8482	979	8.7:1
1986	4443	5313	9756	1071	9.1:1

*Not Available.

Table 1

⁶⁰Registrar's Report, Statistics for 1946-1987, Massachusetts Institute of Technology, Cambridge, MA.

APPENDIX C

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