



**Worcester Polytechnic Institute:
Pre-Construction
Management and Design Services
for the
New WPI Residence Hall**

A Major Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

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ABSTRACT

This project documents the development of the preliminary design of the New WPI Residence Hall building. As the design evolved throughout its early phases, several cost estimates were performed and analyzed for each design alternative. Preliminary cost estimates were generated using traditional parametric methods as well as information generated by a Building Information Model created with Autodesk REVIT. A comparative structural analysis was performed to accommodate load requirements demanded by the construction of a future green roof for the building..

AUTHORSHIP PAGE

This Major Qualifying Project was developed by four undergraduate students who each contributed equally to all aspects of the project. Also involved was Victoria Lartey, a graduate student at WPI, who worked in conjunction with the group in contributing to the REVIT drawings and sections of the paper. Ms. Lartey has produced a separate report documenting her activities.

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We would like to acknowledge and thank all who helped us throughout our project, especially our advisor Professor Guillermo Salazar for his direction and guidance. We would also like to thank the architect, Cannon Design and the project management firm, Gilbane Building Co. for their guidance during this work and allowing us to sit in on their bi-weekly meetings with WPI. Furthermore, our group would like to acknowledge WPI for their support and willingness to provide the necessary information for our report, especially Naomi Carton, Philip Clay and John Miller.

CAPSTONE DESIGN STATEMENT

The capstone design requirement for this Major Qualifying Project was satisfied by investigating the structural implications of the incorporation of a green roof to the design of the new residence hall at WPI. Both the basic structural steel roof system and a steel roof system to support the additional loads of a green roof were designed, priced and evaluated for a cost vs. benefits analysis.

We used the Load Resistance Factor Design Method to first determine the sizes of the structural steel members. The loads used in design are provided by the Massachusetts building code and in consultation with Cannon Design. Once the design loads were determined the design moments were calculated. This was used to determine plastic modulus which was then used to size the members of the roofing system. Using the RS Means Cost Data book the unit prices of each of the members were found. To estimate the cost of structural steel the unit price was multiplied by the length of each member and then totaled. The concrete slab was the same for both roof systems and was estimated by multiplying the unit price per cubic yard. The green roof has a 4" layer of soil which was priced using the same method as concrete. The final cost of each system was found by adding the appropriate components of each roof together.

The following constraints listed by the ASCE were addressed in this capstone design component:

- **Economic**

The feasibility of design of the green roof is determined by comparing the cost of steel for the green roof to that of a regularly loaded roof. The increase in steel sizes for the green roof would greatly affect the cost of the project if built for this purpose. The additional cost

comes not only from the added steel, but also from other materials including soil, plants, equipment, and labor to complete this additional work.

- **Environmental**

In providing the building with a green roof enables the building to reach a higher LEEDS rating making it more environmentally friendly. This rating determines the level of environmental soundness a building has achieved. The plants and overall green space will be a positive addition to the structure.

- **Constructability**

The use of steel as the primary structural material for the roof makes this project easier because of the steel is more readily available than pre-cast concrete in the Worcester area. The material is also highly adaptable so it can be changed to follow many different guidelines and to fit into several different situations. Since the construction of a green roof can take more time on a project, preparations can be done during fabrication to save time during construction, for example, pre-welding bolt plates to certain beams in the shop reduces installation time in the field.

- **Sustainability**

This roofing system was designed out of steel, a material which is known to last a long time under normal conditions. This insures the sustainability of the roofing system under these two different possible loading conditions. Any roofing addition to the residence hall will lead to the beautification of the property, as well as keep it up to date in the future efforts to support the environment and in order to keep the building energy efficient.

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1.0 Introduction

As the Worcester Polytechnic Institute (WPI) begins to follow through on its long term goal of expanding its student number by an unknown amount, the need for further student housing is one aspect of the plan that needs to be addressed immediately. The lack of housing for upper class students has become more apparent in the past five years. Recent numbers have shown that over 47% of the WPI student community, of all years, is living in off campus apartments¹. However, this is not a problem solely for the upper class students anymore. As WPI plans to expand their number of incoming freshman, it is necessary to figure out where these students will be housed after their first year at this university is over. Currently 715 beds are saved specifically for freshman students², but as the number of incoming students increase, this number of beds will also have to be adjusted. Just last year, from Fall 2005 to Fall 2006, the number of incoming freshman increased from 735 students to 780 students. Even with taking into account the fact that not all students will live on-campus (some commute and some will start their freshman year in off-campus apartments); holding only 715 beds is not enough. For example, even now with only 780 students in 2007, freshmen were put into ‘forced triples’, which is a standard double room accommodating three students, rather than the normal two. Typically, after students swap rooms and find other housing, the ‘forced triples’ work themselves out. Even with increasing the number of students in small increments, which is what WPI is trying to do, there is still a strain put on the current housing availability.

In order to remedy this housing situation and allow for further growth, WPI has proposed that a new residence hall be built between Boynton and Dean Street. It has been suggested that a 200-300 bed dormitory is needed to meet the housing demands of the current and future student body. Since new beds will be added to the campus, the Massachusetts Building Code dictates that parking must

¹ As per interview with Philip Clay and Naomi Carton

² Ibid

also increase in direct proportion to the bedding. While construction will already be taking place, WPI suggested that it would be a good time to improve their current parking conditions overall to alleviate the issues of limited parking on campus. Although, the new residence hall creates an opportunity to improve other problematic areas from the past, the new residence hall also creates issues of its own. Some issues created by the residence hall include but are not limited to the need for further parking spaces, outdoor gathering areas, classrooms, budget and aesthetics. These issues may be addressed as the WPI Master Plan continues progress. WPI is striving to expand their campus, but is facing difficulty working with the space limitations due to their land locked location.

Our group's foremost task was to run in parallel some of the responsibilities of construction project management firm, Gilbane Building Co., throughout the design and development phases of this proposed project. Most of the work was done in the pre-construction phase where the analyses of several schematic designs were studied and one final design was chosen. The responsibilities for Gilbane throughout this early part of the process included scheduling, cost estimating, budgeting and providing constructability feedback on design to the architectural firm, Cannon Design of Boston, MA, the construction management firm, Gilbane Building Co. and Worcester Polytechnic Institute. In order to accurately carry out these tasks, our group used such programs as Excel for cost-estimating and Autodesk REVIT for creating 3-D models and as a secondary measuring tool. We also attended meetings and took minutes on the progress made in construction decision-making, as well as spoke with representatives for Cannon Design, Gilbane Building Co., and WPI.

The final deliverables for this project include 3D models created from preliminary design configuration presented by the architect, a structural design of alternative roofing options considering the possibility of a green roof construction for the building (which is used as our Capstone Design portion), a detailed analysis of cost estimating and a case study of the progress made on the new building from August 2006 to February 2007. The intention of this report was to make the tracking

of the progress made in the six months easy to follow, as well as give additional estimating methods and structural roofing options.

2.0 Background

There were many aspects that WPI had to consider when this project was first presented. Time and money were high on the priority list therefore a team needed to be put together of a management firm and architect that could come on board early in the project and understand many of the different methods used in budgeting time and money.

2.1 General Construction Management

Project management is the art of directing and coordinating human and material resources throughout the life of a project by using modern management techniques to achieve predetermined objectives of scope, cost, time, quality, and participation satisfaction. The basic components of project management include knowledge of general management and familiarity with the special knowledge related to the project.

Construction Management is a project delivery method where the client entrusts a construction manager to provide certain preconstruction expertise including cost estimating, value engineering, and scheduling and, during the construction phase of the project, coordination of all construction activities. The management of construction projects requires knowledge of modern management, as well as an understanding of the design and construction process. Construction projects have a specific set of objectives and constraints. Generally, project management is distinguished from the general management of corporations by the mission-oriented nature of a project.

Construction Management encompasses a set of objectives which may be accomplished by implementing a series of operations subject to resource constraints. There are potential conflicts between the stated objectives with regard to scope, cost, time and quality, and the constraints imposed on materials and financial resources. These conflicts should be resolved at the onset of a

project by making the necessary tradeoffs or creating new alternatives. Subsequently, the functions of project management for construction generally include the following:

- Specification of project objectives and plans including delineation of scope, budgeting, scheduling, setting performance requirements, and selecting project participants.
- Maximization of efficient resource utilization through procurement of labor, materials and equipment according to the prescribed schedule and plan.
- Implementation of various operations through proper coordination and control of planning, design, estimating, contracting and construction in the entire process.
- Development of effective communications and mechanisms for resolving conflicts among the various participants³.

Project Management focuses on the following measures to ensure an organized project:

- Integration management to ensure that the various project elements are effectively coordinated.
- Scope management to ensure that all the work required (and only the required work) is included.
- Time management to provide an effective project schedule.
- Cost management to identify needed resources and maintains budget control.
- Quality management to ensure functional requirements are met.
- Communications management to ensure effective internal and external communications.
- Risk management to analyze and mitigate potential risks.
- Procurement management to obtain necessary resources from external sources⁴.

2.2 Construction Manager at Risk

Construction Manager (CM) at Risk is a construction delivery method in which a construction manager/general contractor is brought on during the design phase to be part of the design team and to propose a guaranteed maximum price at or towards the end of the design development phase. The CM is chosen based on qualifications, and then the entire operation is centralized under a single contract. Since the client hires the construction manager based on qualifications, it ensures a construction manager with a strong allegiance to the client, because their relationship involves strong references and repeat work.

³ List from Hendrickson, Christopher. Project Management for Construction. Prentice Hall, 1998

⁴ Ibid.

The architect and CM work together in order to cultivate and assay the design. Then, the CM gives the client a guaranteed maximum price (GMP), and coordinates all subcontract work. Cost savings can be realized in a number of ways. By hiring the CM during the design phase, early coordination is possible, which can increase the speed of the project and strengthen coordination between the Architect/Engineer and the CM.

The CM firm will be performing significant portions of the design and construction administrative services. In doing so they expose themselves to risks associated with quality, cost, and schedule. In this type of contract, the liability for the success in completing the project on time and in budget lies with the CM and not with the owner. Transparency is enhanced, because all costs and fees are in the open, which diminishes adversarial relationships between components working on the project, while at the same time eliminating bid shopping. This type of work also allows for a ‘fast track’ method of delivery because the CM is involved so early on in the project.

2.3 Fast Track Process

The normal process of construction scheduling involves the performance of a series of activities, in a predetermined sequential order. The customary logical order of these functions is, design, bid and negotiation, contract award, construction, and ultimately, completion. Each activity in this method must be virtually completed before the next may be commenced. To perform all of these functions will take a certain amount of time, extending the overall time of the process⁵.

Fast tracking is a project management technique used to ensure that projects are completed within the shortest time possible. The usual way of shortening the time scale is by increasing productivity, that is, by completing each function as efficiently as possible and starting each new phase immediately upon completion of the preceding phase. Everything is done in proper order and no time is wasted.

⁵ O’Leary, F Arthur. Fast Track Construction

When projects are "fast-tracked", it indicates that the total elapsed time of the project will be decreased by compression of the time schedule. This is done by overlapping some of the functions, doing two things at the same time. This would be accomplished by starting a new phase of work where possible before the preceding phase is completed. Time saved by concurrent work will accumulate and appear at the end of the construction period in the form of early overall completion⁶.

Organizing the project to produce early completion by the technique of concurrent or overlapping time scheduling is the essence of fast track construction. The usual procedure for overlap functions entails the contractor's or construction manager's earlier involvement in the project is necessary.

2.4 Preliminary Cost Estimating

There are many different types of estimates that are done throughout the different stages of a project. Feasibility estimates, although less detailed and before pre-construction estimates, play a significant role in defining the scope and benefits that will occur from undertaking a specific construction project. Since this estimate is created so early in the construction process there are usually no drawings or preliminary plans in which the estimator can use. Due to this factor the estimator must use his/her knowledge of construction, economic shifts, and accounting to create the feasibility estimate. This type of estimate shows the benefits that the project will bring versus the cost that will be incurred.

An alternative to determining the benefits of a project is to find out what the project's approximate cost will be by the use of reference books. These books, an example R.S. Means, give the cost per square foot for various types of buildings. But the estimate should not solely depend on the numbers from the reference books. These books give an average square footage for many geographic areas, when in reality a building in Los Angeles, CA and a similar building in Worcester,

⁶ O'Leary, F Arthur. Fast Track Construction

MA will vary in cost. It is also very unlikely that the building being estimated will have identical components of the estimated building that is priced in the book. For these reasons further investigation will be needed to increase the accuracy of the projects costs. These books are useful though because they provide it is a quick way in which to determine if the cost of a project is within the budget of the owner. Other project costs that need to be determined and included in the feasibility estimate are the one time fees that will add to the project costs. These include such costs as land acquisition, design fees, and construction costs.

An estimate that has reasonable accuracy is called a pre-construction estimate. It is created once more information on the project is known in order to see difference in cost that the modifications will cause. This is used to keep the project within the owner's budget but allowing for the optimum alternatives to be used.

3.0 Case Study

WPI has been considering a project such as this for many years now but began actual planning in the summer of 2006 when they began to take serious steps to make this vision a reality.

3.1 Background

The members of the Residence Hall Planning Committee, RHPC, first had to look at the history of the need for this building to get an understanding of what the campus would require. After the decisions were made for a general direction of the building, WPI enlisted the help of others to continue to plan and build.

3.1.1 History of Residence Hall

In the fall of 2006, WPI opened its campus to 780 new freshman students, the highest number of accepted students in WPI history. While it may seem large to those familiar with WPI, it is still small compared to other schools. Historically, the average number of students accepted as freshman was 715 over the past six years. The numbers ranged anywhere from 705 students in 2001 to 780 in 2006, the lowest being 633 in 2003⁷. For example, another engineering and science college technical school, Massachusetts Institute of Technology (MIT), located in Boston had 1,513 students admitted for the Fall of 2006 school year⁸. Another example, Holy Cross, which is a nearby college in Worcester, admitted 2,270 students for the Fall of 2005⁹. The smaller school atmosphere with fewer students is what WPI prides itself on and may never reach a freshman class of 2,000 students. The small, close-knit campus may be why one of the reasons some students choose WPI over other schools, however that same small campus can be limiting.

⁷ As per interview with Philip Clay and Naomi Carton

⁸ http://www.mitadmissions.org/topics/apply/admissions_statistics/

⁹ <http://www.holycross.edu/abouthc/glance/>

WPI has a vision for the expansion of its campus and its 20 year “master plan” depicts the broad outline¹⁰. Included in this master plan is the new Admissions Building, has been recently built, as well as a new sports complex and new residence hall. Although this plan has been presented, it is only a general idea of what is to come and not all steps will be carried out exactly as stated. With the completion of the new admissions building, now known as the Bartlett Center, the next step in the master plan is the construction of a new residence hall. It has become more apparent to the administration and faculty in the past five years through studies and surveys that there has not been enough on-campus housing for students of any year. Part of the overall improvement of the campus in the master plan, is being able to create more of a “community”. Our campus and residential housing should be able to bring students together, rather than push them off of campus after freshman year.

Currently WPI only houses about 47% of their enrolled undergraduate students and guarantees housing for only first year students¹¹. There are five residence halls that currently house freshman students and approximately 715 beds out of the 1243 beds on campus are saved specifically for these freshman students¹². After a student’s freshman year, they are on their own to decide whether to enter a “housing lottery” to see if they are picked to fill the remaining beds not taken by incoming freshman. Or if they decide not to enter this lottery or are not chosen for housing, a student can decide to try to find an off campus apartment or move into the fraternity or sorority house that they are associated with. However, finding housing elsewhere off-campus may not be as easy as it sounds. The Greek housing only has room for 490 of their associated students¹³ and while it may be difficult to find an apartment in any area surrounding a higher educational school, it is especially hard for WPI students in Worcester. There are at least 5 other colleges in a 10 mile radius of WPI

¹⁰ <http://www.wpi.edu/Master/>

¹¹ As per interview with Philip Clay and Naomi Carton

¹² Ibid

¹³ Ibid

and our upperclassmen seeking housing compete with these other students for the limited renting options.

These housing issues have become more prominent in the recent years, with the number of accepted students growing an average of 15 percent over the past 5 years. As Figure 1 shows how the number of incoming freshman has gone up and down but ultimately there has been an increasing amount of students coming to WPI.

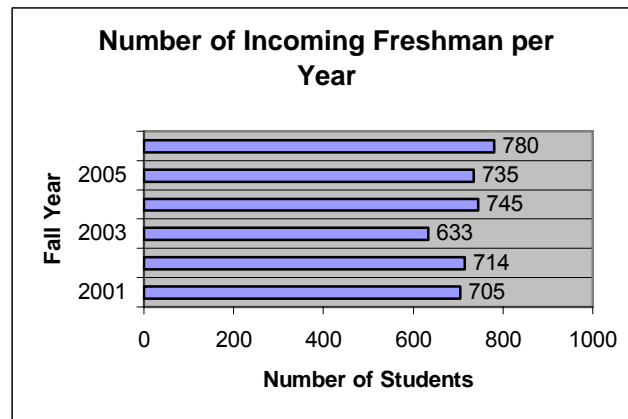


Figure 1 - Number of Incoming Freshman per Year¹⁴

Although, WPI isn't planning on greatly increasing the number of accepted students at this time, the growth rate that the university is maintaining is exceeding the current student accommodations.

3.1.2 Planning for a New Building

The selected administration, faculty, trustees, and students, that have been working the implementation of the new building since 2004, comprise what is known as the 'Residence Hall Planning Committee' or RHPC. The committee began with taking a survey to get a student's perspective on what kind of dormitory would be appealing to them, as well as what amenities they would like to be included. A total of 1,081 undergraduate students responded to this survey,

¹⁴ As per interview with Philip Clay and Naomi Carton

indicating that the most desirable option for a new dormitory would be one with apartment style living. The most important amenities that these students would like to see incorporated into the new building were network/cable/phone and onsite parking. Next, keeping in mind the surveys results, (which can be found in Appendix A), the RHPC visited other colleges in the early summer of 2006 to tour their residence halls. They looked at upperclassmen residence halls that had suite style living in order to decide on which specific set up and amenities would best fit the needs of WPI.

During mid- summer 2006, after considering different sites on and near WPI's campus, it was decided that the new residence hall would be built next to Founders Hall in the "lower" part of campus. This was decided because the site was currently a parking lot and housing for non-college affiliated Worcester residents and no students would be misplaced during the construction of this building. Another location that was considered was the lot that Salisbury Estates, an apartment complex on Park Ave. which rents 75% of their units to WPI students, is currently located on (Refer to Appendix B, to get a better insight of the location of this proposed site). However, this option eliminated housing in order for the new structure to be built and the administration did not want to displace students during construction. By erecting a new residence hall without displacing students, WPI could use this new building to re-house students later if another residence hall is needed.

After the decision was made on where to place the building, further specifications needed to be addressed as to how big the building would be, how many students would it sleep and what other educational rooms could be implemented into the new residence hall. In order to make the building worth while to build, a certain amount of beds would be needed to fit. A committee looked into the current needs of the institution and came up with 200-300 beds would be necessary to address the present issue of housing. This number justified the erection of the building without being too extravagant and over planning. It was also decided that the new building could be home to extra educational and study rooms for upper-class students to enjoy.

3.1.3 Planning for Parking

The new residence hall not only called for on-site parking as part of the design but also created a new issue related to parking needs for the campus at large. By erecting the building on this site, which currently is used for parking, WPI is actually eliminating approximately 100 spaces because the proposed site for the new residence hall actually sits on an existing 100 space parking lot. Furthermore, the new residence hall also creates the need for additional parking spaces. Since parking requirements are determined by the number of beds and classrooms on campus there has been a ratio set of 1 to 3, cars to beds, respectively. This is saying that for every three beds, there must be one parking place. As was decided, WPI plans for 200-300 beds, creating the need for 67-100 cars. Consequently by the end of the building's construction there needs to be a permanent parking solution that will be able to hold spaces for approximately 200 vehicles, this number will account for the 100 spaces lost due to construction and the additional 67-100 spaces that will be required for the residence hall.

3.1.4 Architectural Involvement

By the mid-summer of 2006, WPI took the first step for this idea to become reality and began interviewing architects. Approximately seven architectural firms were considered at first, but were narrowed down by qualifications and presentations made. Ultimately, it was decided that Cannon Designs, of Boston, would be the firm that would create a design for a new residence hall intended for upper-class WPI students. The guidelines for the building were voiced to the architect and included the decision that the building should bed approximately 200-300 students, depending on how large the building would ultimately be. Any less than this number would be too costly without fully solving the housing issue.

3.1.5 Construction Management Involvement

After the architect was chosen, WPI then began searching for a construction management firm to come on board in the project. It was necessary for the CM to begin involving themselves with the project so early on because of the possible need for a ‘fast track’ method of delivery. The RHPC went through the same process to choose a CM as they did for the architect. Approximately ten construction management firms were initially looked at, and then were narrowed down to three. This decision took more time than the architectural choosing because WPI had previously worked with more than one of the firms presenting, making the decision more difficult. In early October 2006, the RHPC decided that Gilbane Building Co. from Providence, Rhode Island, would come on board and provide the necessary services for the new building. WPI was familiar with this company, as they had just finished the new admissions building on campus. Gilbane immediately began with pricing out some of the options that Cannon had begun presenting and also made a preliminary schedule.

3.1.6 Site Acquisition/Pre-Construction Requirements

In order to reach this project’s particular objectives, certain preliminary measures had to be taken before construction commenced. One of the first objectives is the acquisition of land. Due to the limited availability of land in and around campus, construction of this residence hall required the acquisition of a building located at 35 Dean Street, Figure 2, which WPI did not own. This building will be demolished so that the new residence hall may take its place, however WPI did not own this property. Until recently, this building was home to the WPI Campus Police and rent was paid to a WPI alumnus for the use of the building. Negotiations commenced immediately for the acquisition of this parcel of land after the decision was made on

the location of the new residence hall. Also needed to be demolished are 39 Dean Street and an apartment building on 30-32 Boynton St. that WPI already had ownership of.



Figure 2 – Map of Proposed Site

The construction of the proposed building also requires the relocation of offices and residences. In some circumstances this relocation will be permanent, while in others it will only be temporarily. Some of the offices that need to be relocated include Campus Police, which moved temporarily to Founders Hall, as well as Administrative Services, WPI Bioengineering Institute, and Graduate Admissions located at 39 Dean Street, see Figure 2. In total these offices require between 6,000 and 7,000 square feet of free space to be temporarily placed.

This project also requires the permanent relocation of some of the residents of 30-32 Boynton St (Figure 2). This is another apartment building, which needed to be demolished in order to have the free space for the new residence hall. This building not only held WPI students, but also housed

residents that were not affiliated with the college. Notice was given early on to the residents of this apartment building in order to give them adequate time to find new housing.

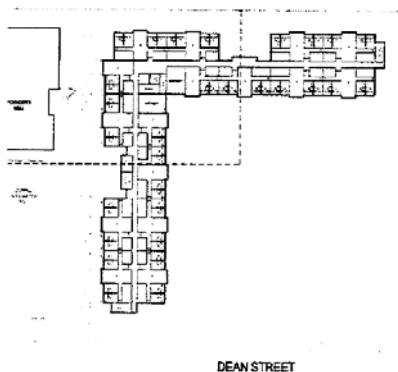
Lastly, the City of Worcester imposed constraints on the construction of this building that needed to be addressed before approval for ground breaking was granted. One issue that needed to be addressed involved zoning laws. There are many different zones on a city street, each with its own guidelines that the buildings within the zone must follow. The zones in this plan must be altered in order to keep the new residence hall within the “institutional” zone, refer to Figure 2 for zoning lines. If the zones are not altered, a majority of the new building will be in the “residential” zone, RG-5 and this will affect the maximum height allowed of the proposed building, limiting the building to a height of 45 feet.

3.2 The Design and Development Process

In order to begin the process for creating a new residence hall on the WPI campus the architects at Cannon Design, met with the RHPC in early August in order to confirm the necessary parameters of the project. The initial requirements for the building issued the need for suite style rooms, separation of toilet room and showers, kitchens, single and double bedrooms and the necessary parking required by the city. WPI also requested that there should be no more than 4 bedrooms per suite, and that there should be an apartment for a Professional Residential Staff member. Also there should be academic/meeting rooms for students or faculty to gather. The common area should be separate from the kitchen and include either an eating table or a “bar” style counter space with stools. The bathrooms should include a separation of the toilet area and shower area but could be close in vicinity. Discussions also took place about having two sink/mirror areas for students to use on opposite ends of the suite.

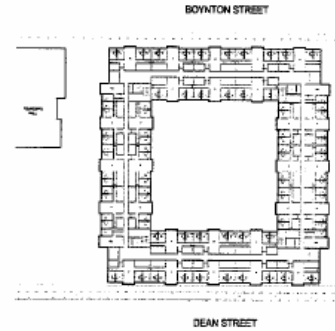
The first floor of the building will be home to the common areas, including exercise, game, community, music and laundry rooms. In the preliminary design, there was also a call for the integration of technology suites on each floor, as well as student lounges. These additional rooms allowed for adequate support of the academic needs of upper-class students. WPI also asked the architect to allocate classroom or activity room space in order to be home to certain summer programs that the university holds. Part of this request included the prerequisite of an air conditioning system in the building to make the summer program more comfortable to its student groups. This required at least 4,000 NSF of space in the building.

Initial building schemes for review by the RHPC between August to October and consisted of a 5-6 story “U” shape and a 4 story “O” shaped option, refer to Figure 3. Each of these met the 300 bed requirement and allowed for the opportunity for underground or structured parking for the 200 cars. Even though these building met the initial criteria, issues arose with the schemes. Some of these issues were the building’s height, the amount of free space around the building, and the need for exploration of other alternate options stemming from the “U” shaped building.

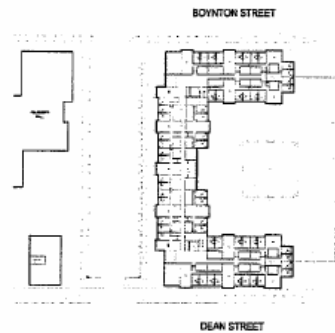


5-story L Option

Figure 4 - "L" Shape



4- story O Option



5-6 story U Option

Figure 3 - "U" and "O" Shape

During the exploration for alternatives, a 5 story “L” shaped building was added to the possibly building choices, refer to Figure 4. Cannon continued to explore design alternatives along with several different building orientations to allow for maximum sunlight exposure to the building. The “L” and “U” shaped schemes were of interest to the RHPC, along with some additional design parameters that needed to be addressed. They include the

orientation of the building if there is to be a green roof, keeping the sub-grade of the parking garage above the water table, and the connection of the new structure to Founders and the future café.

In order to assess the two proposed schemes several unit floor plans were created. The units were to include 4 single bedrooms with a full kitchen and eating area, as per the request of the students, see Figure 5 for examples. These units were then used in both plan layouts for consistency. The two plans presented were the “L” shaped and “U” shaped building both at 5 stories. The RHPC was asked to evaluate the prospect form each of the schemes. Both options were discussed and concerns arose regarding the building’s height and massing being out of scale with the rest of the neighborhood.



Figure 5 - (left to right) Single Room, ADA Single Room, Double Room, Studio Room

It is at this stage of the project, in early October, that the construction management firm, Gilbane Constriction Company, came on board and the project’s budget was seriously discussed. It became a challenge to integrate all of these things into the project and to keep it with in the planned budget. Cannon, once again, changed its design to accommodate the revisions due to the building cost. This resulted in a building with a different room count and different unit layouts. The RHPC agreed with these changes but also suggested that the square footage could be reduced in order to

downscale the building and assist with decrease of the massing of the building which seemed to be in disproportion with the building landscape of the area.

The committee preferred the 5 story “L” shaped building, but the RHPC was not confident with the approach without the input of Dr. Berkey, the president of the Worcester Polytechnic Institute. At a separate meeting with Dr. Berkey in November, the project was lead into a different direction. The project was greatly downscaled and several new directives were included. The major changes included: the building height being 4 stories (5 maximum); accommodations for 240 beds and 150 parking spaces; hiding the parking garage under one level; providing a mixture of bedrooms with doubles and singles in some of the units; and the removal of campus police from the new structure.

As a result of the President’s directives, 5 concept alternatives were created by Cannon, right before the New Year, to meet these new requirements. Each provided a bed count of 220-236 and approximately 150-175 parking spaces. Of the 5 schemes considered Options A and E were chosen to investigate further. These options allowed for a symmetrical building, open green space, and reduced interior travel distances. Option A was an “H” shape, refer to Figure 6, which

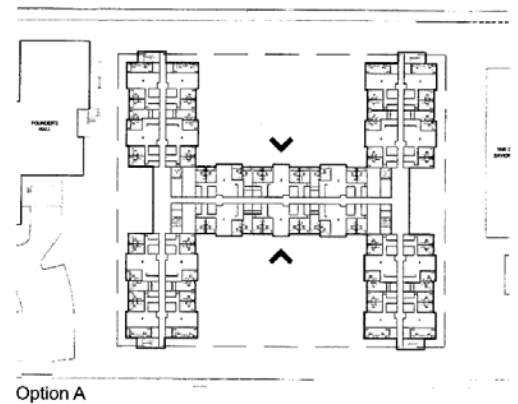


Figure 6 - "H" Shape

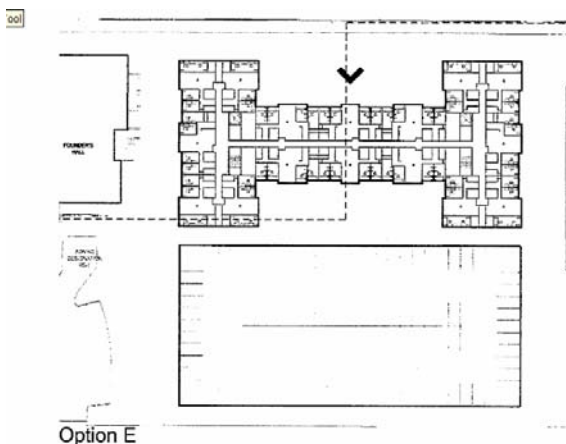


Figure 7 - "I" Shape

included an underground parking lot for 150-200 cars. The building itself would be 4 stories high and about 88 beds per floor. Option E was an “I” shape, refer to Figure 7, with a 2 level detached parking garage along Dean St. It was a four and five story building with about 220 beds. Cannon worked in conjunction with

Gilbane to review cost implications of both schemes in terms of size, exterior facade, and structural materials.

When these two final schemes were presented again, Gilbane presented cost information for both schemes which indicated several price increases associated with Option A in terms of the underground parking and the building area. Also, it would be difficult to use Option A and stay within the project's budget. It was determined that Option E was the preferred scheme and it was decided by all that the design should be estimated and developed in further detail.

As with most construction projects, there are many contingencies on which the project is based upon. Any discrepancy in these contingencies could cause a delay in the overall project and affect the August 2008 move in date. With this particular project, the architect, Cannon Design, released a preliminary schedule in early August. When the Project Management Firm, Gilbane, got involved in mid November they also released a preliminary schedule. In general, the schedules did not differ tremendously, but did have a few activities that were pushed back and scheduled to begin at a later date.

The pre-permitting activities were scheduled, as per Cannon's schedule, to be completed in early October. However, because there were still major designing issues to be decided on at this point, nothing was concrete enough to be brought to the attention of a building inspector or city officials. Gilbane's schedule reflected this delay and moved the completion of pre permitting to March 12, 2007. Next, the schematic design phase was extended by Gilbane until February 9, 2007, rather than the late December date from Cannon's schedule. This change was made in order to give Cannon and WPI the time to prepare and issue the schematic design scheduled by Gilbane from November 20, 2006-January 11, 2007. This directly relates to why the Design Development Phase was also pushed back on Gilbane's schedule.

The biggest difference in the two schedules, as well as the schedule that was released from Gilbane on November 22, 2006, is the acquiring of 35 Dean St. This is currently rented to WPI by an

outside owner and used as the WPI Police building. Originally, the building was set to be bought by late September. Later the date was pushed back to the end of November, one month later. The next schedule however, placed the deadline on December 29, 2006. Throughout this whole process, all companies involved had to keep in mind that the acquiring of this building was essential for the project as most of the parking garage sits on that particular lot. So as one would imagine, it was great relief to the parties when the property was finally bought in early February, nearly 4 months after the original date. This and further scheduling differences can be seen in Appendix C.

4.0 Preliminary Cost Estimates

Cost estimating, which is one of the main responsibilities of a Project Management Firm throughout the pre-construction phase, gives the owner an idea of the price for the different designs presented by the architect. It is a vital part of the conceptual designing phase because it helps to define the scope of the project, as well as narrow down the designs to a feasible proposal. This task is continuous as the prices change throughout the project with each alteration of the design.

4.1 Phase One

Although there are not definite plans or a firm direction during the early phases of a project, cost estimating still plays an important role. It allows a Project Manager to give the owner a better idea of where the total price will be. Estimates also allow the owner to see how changes can affect a budget and allow for a means of cost vs. benefit analysis.

4.1.1 Phase One: Method of Cost Estimating Structure

Cannon Design presented WPI with several different building configurations, which was used as a basis for measuring to get the preliminary totals for building costs. To aid in the development of preliminary cost estimates of the design alternatives produced by the architect, the 2D plans were recreated in 3D using the program AutoDesk REVIT. This help to better visualize the designs and was used at this stage for a more accurate measuring of the approximate square footage for each floor. Although, one can measure using a scale and a calculator, it was more time efficient to enter it into this program because revisions made to the drawings could alter the square footage and the program would mirror those changes numerically.

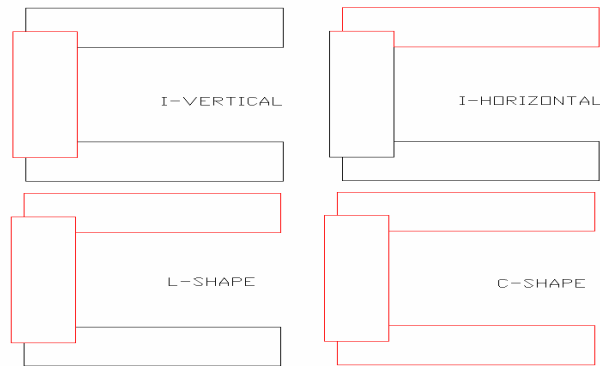


Figure 8 - Shapes for Measuring

When the drawing was viewed from a 3-D aspect, it was clear that the building could be broken up into 4 different shapes which are highlighted in red and shown in Figure 8. The shapes are named after the letters that they most resemble I, L and C, and are used as a reference to obtain a more accurate measurement of the building. From there, the 1998 RS Means book provided reference prices per square foot. However because of the year of the book adjustments had to be made due to inflation for the past 9 years using the equation: $(\text{Price/ Square Foot}) \times ((1+\text{inflation rate})^{\text{amount of years}})$. Using an average inflation rate for the construction industry on 5.3%, the equation came out to be: $(\text{Price/ Square Foot}) \times (1.053^9)$. The newly adjusted price was then interpolated to get a total square feet closer to what the building was estimated to be. Excel was used for this task by graphing each price given in the RS Means book in order to get a “line of best fit” and its formula, in other words Excel was able to output an equation for the line of best fit for the prices vs. square footage. Then the total square feet that was estimated per floor was entered into this formula and a more accurate price was obtained. In order to obtain the highest level of accuracy, two graphs were plotted to correspond with the two pages of prices in the RS Means book, one for a 2-3 story building and another for a 4-8 story building, shown in Figure 9.

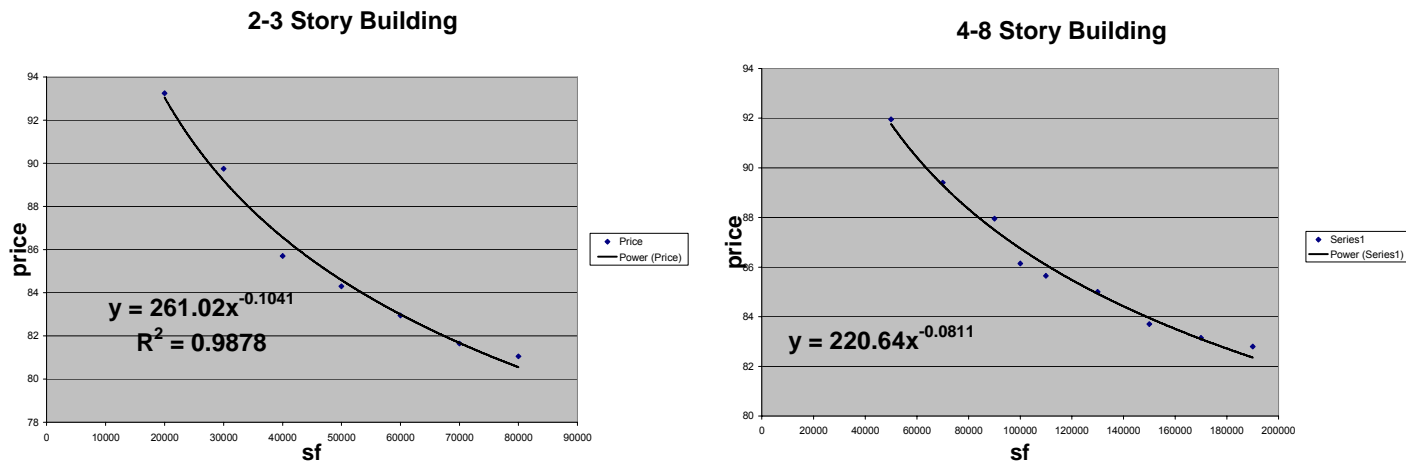


Figure 9 - Lines of Best Fit for Pricing

The 6 different schemes that Cannon presented, as in the following 6 figures, were priced using 2 different methods. The first method consisted of pricing the building storey by storey. Each storey was assigned a shape and using its respected shape and square footage, the cost per floor was estimated. This was done by multiplying the approximate square feet by the cost per square foot obtained in the interpolation. After calculating the cost per floor, a preliminary total was found for each of the 6 schemes.

In the second method, each wing of the building was treated as a separate entity. These were labeled by the cardinal direction that it faced in relation to The Church of our Savior of Worcester, as seen in the map in Chapter 3. Using the interpolation method, new prices were found for our new total areas. A total square footage was calculated for each wing and multiplied by the price found for that respected area. These total prices for each wing were then summed in order to again get a preliminary total for each given scheme. Worksheets that contain both methods along with a rendered drawing can be found in Appendix D.

Although there are variations in the prices when using the 2 different methods, there was not a significant difference but it seemed that method one was more accurate and lower in price. Listed in Table 1 are the prices calculated for each method.

	# of Beds	Method 1	Method 2	Cost/Bed
Scheme		(price in millions)		(method 1)
1	290	\$22.88	\$23.42	\$78,879.42
2	268	\$20.69	\$21.88	\$77,202.97
3	290	\$21.28	\$21.65	\$73,388.41
4	280	\$20.66	\$21.95	\$73,775.25
5	294	\$22.44	\$23.37	\$76,328.44
6	282	\$20.15	\$22.41	\$71,436.45

Table 1 - Structure Cost Analysis (Summary I)

Using this table and the prices obtained, it seems that the best option for the new residence hall would be Scheme 4. While it is not the lowest total estimate that was calculated, it does fall within the lowest 3 out of the 6. Also, by looking at the 3-D model of each scheme through REVIT it was decided that aesthetically, Scheme 4 would look the best in relation to the nearby structures. Scheme 4 has gradual increase of storeys, so that the building seems to be less intrusive and overbearing and furthermore, the higher storeys will allow for more attractive views of the environment.

4.1.2 Phase One: Method of Cost Estimating Parking Garage

While a majority of the cost estimating of this project is focused on the building itself, there are other parts of the project which will account for a considerable portion of the total cost. The cost estimation of the parking garage was done much like the cost estimation of the structure and floor plans, using the RS Means book to find a total cost of the garage. First, an approximation of the total square feet of the proposed parking garage was found. Then using the method of interpolation by taking the cost per square foot of two different sized parking garages found in the RS Means book,

one bigger and one smaller than the proposed garage. With this cost per square foot and the total square feet of the garage, an estimated cost was determined which was then adjusted for inflation.

A summary of the final cost of a garage is shown in Table 2 below. and the worksheets can be found in Appendix E.

2 Story Parking Garage

Total square feet	63860
Cost/square foot	\$65.26
Total cost	\$4,167,428.06
Total cars	196
cost/car	\$21,262.39

Table 2 - Parking Garage Cost Analysis (Summary I)

4.2 Phase Two

After these six schemes, shown in figures above, from Phase One were presented to the President of the University, some changes were made in order to accommodate his suggestions. The footprint of the building began to reduce in size, therefore reducing the number of beds that the building was originally designed for. In order to compensate for the number of beds lost, a new idea of having a mix of single and double rooms in the suites was explored. Many of the board members were partial to a ratio of 30% double bedrooms, to 70% single bedrooms. Also, the heights of the buildings were out of the zoning allowances, therefore buildings needed to be fewer storeys high. In order to be more respectful of the neighboring houses, as well as the next door church, it was suggested that the largest mass of the building be faced toward Boynton St.

or Founders Hall. Also, the shapes that were presented originally had to be reviewed for changes because the shadows that were produced had negative effects on the neighbors. More “green” and open space was to be integrated and housing the campus police in the new residence hall was no longer a condition. In order to break up the long hallways and allow for more convenient access to the elevators and stairs from all ends of the building, “cut backs” were added in the middle of the hallways. These glass recessions in the hallways also allowed for more natural light to pass into the halls. The following schemes were presented to be further explored by the board.

4.2.1 Phase Two: Method of Cost Estimating Structure

As the configurations of the building shifted to better fit the needs of WPI, estimates need to be recalculated with the revised information. Now we have options A-1, A-2 and E, shown in Figure 10 to the right, as our building configurations. The same preliminary methods were used in order to obtain the square footage costs in terms of REVIT and interpolation of the RS Means values.

The three new options were priced by using the same estimation methods for pricing Phase One of the project. Method one consists of dividing the building into separate entities based on the number of floors and the natural divisions in the building. The area of one floor was calculated, and then multiplied by the number of floors in that particular building to get a total square footage. As the separate total areas were found, a cost per square foot was determined using R.S. Means and interpolating for the given values. A total cost was calculated by multiplying the price per square foot found by the respected area. These total costs were then summed to get a total cost for the entire building.

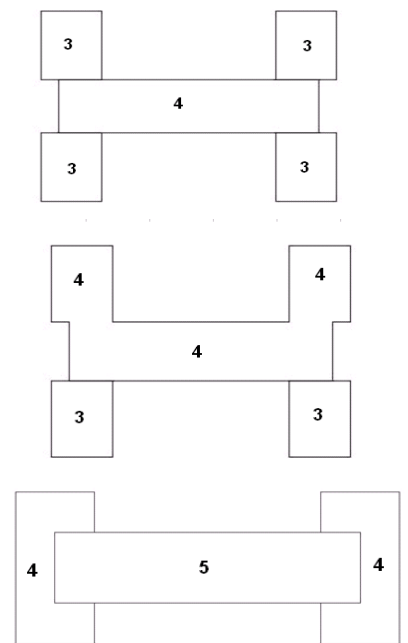


Figure 10 – Options (from top to bottom) A-1, A-2, E

In Method Two the building is priced storey by storey. Each storey was assigned a shape and using its respected shape, the cost per floor was estimated. This was done by multiplying the approximate square feet by the cost per square foot obtained in the interpolation. After calculating the cost per floor, a preliminary total was found for each of the three options. Worksheets that contain both methods along with a rendered drawing can be found in Appendix F.

	# of Beds	Method 1	Method 2	Cost/Bed
Scheme		(price in millions)		(method 1)
A-1	232	\$16.88	\$16.77	\$72,758.62
A-2	200	\$15.37	\$16.06	\$76,850.00
E	216	\$15.48	\$15.49	\$71,666.67

Table 3 - Structure Cost Analysis (Summary II)

Using Table 3 above and the prices obtained, it seems that the best option for the new residence hall in this phase would be Scheme E. Although it does not allow for the maximum amount of beds, it is the least expensive option. Also, by looking at the 3-D model of each scheme through REVIT it was decided that aesthetically, Scheme E would look the best in relation to the nearby structures. Scheme E has the smallest footprint and allows for a separate structure for parking. Furthermore, it is within the zoning restrictions for height and therefore doesn't cause as many issues with the city as other options.

4.2.2 Phase Two: Method of Cost Estimating Suites

The method of cost estimating individual suites is much like the method for estimating the structure as a whole. In order to get measurements, a room is drawn in REVIT and measurements are taken in order to get a total square footage. The difference in the measurements for suites is that individual items must be measured separately in order to price out the different entities of the room. Each item in the room will be either quantified or measured and a material or specific item will be chosen in order to price out a typical upper-class dormitory. Some of these items include showers, toilets, sinks, counters, cabinets, dressers, tables, windows, doors, chairs and desks.

Other things that need to be taken into consideration when pricing the rooms are the partitions within and around the room. They will also need to be measured and priced out according to the material chosen. The floor area for the different parts of the suite will need to be measured and separated according to type. For example, the flooring in a bedroom will not be the same as in the kitchen or bathroom. These pieces were then priced separately using RS Means Assemblies Cost Data 30th Annual Edition (2005), the worksheet can be found in Appendix G. While none of these specific items have been decided on yet or included in a definite set of plans, it is the job of the project manager to select many different options on their own and then present them to the owner.

4.2.3 Phase Two: Method of Cost Estimating Parking Garage

In phase two of the design for the new residence hall of WPI, two different schemes were looked at. Both buildings were of an “H” design but with different types of garages associated with them. One design called for a larger building footprint with fewer floors. In this design it was decided that the parking garage would be located under the building itself. This approach presents both pro’s and con’s of the design. One positive attribute of this scheme is the visual aspect. By

putting the garage underground you're in turn hiding it and providing a much more aesthetic building. The negative side to this design is, of course, the cost of the project.

The second conceptual design was a smaller footprint building of greater height having more of an "I" shape look to it. With this scheme the parking garage would be separate from the dormitory and be located on the Dean Street side of the building. While having the drawback of seeing the garage, this design proved to be much more economical to the project.

In estimating these two designs, we took the same approach as in our previous garage scheme estimates. The cost per square feet of both garages was calculated by first finding the total square feet of each scheme. We then found the estimated costs per square foot of garages of both greater and lesser sizes. By interpolating these figures we were able to come up with a cost per square foot of our garage sizes. We then adjusted for the inflation rate and calculated the estimated costs for the parking garages of schemes A and E, seen in table 4 below. Worksheets for both garage schemes can be found in Appendix H.

2 Story Parking Garage

Total square feet	65541
Cost/square foot	\$40.68
Total cost	\$4,304,254.92
Total cars	150
cost/car	\$30,554.97

Table 4 - Parking Garage Cost Analysis (Summary II)

4.3 Additional Estimating Procedures

As with several professional companies, our group used many different methods of cost estimating throughout this pre-construction process in order to get an accurate cost in the end. Although our main cost estimating strategy was using the RS Means book, there were also many other alternatives that were taken into consideration when putting a final price on the new residence hall. REVIT was used toward the end of the conceptual design phase as a more integral part of the cost estimating. It became an easier way to extract numbers from the drawings and put a price on individual materials. Other buildings were also used as references to bind the price. Bounding the price allowed our group to know the cost range of what other buildings were in and to make sure our prices were within that range.

4.3.1 Bounding Prices using References

Throughout our project we have refined our estimates week to week in order to track each step of the way to produce a more accurate price. As we continued this process, more details were taken into account and different aspects of the building were looked into.

While the accuracy of a cost estimate is very crucial to any project, there are other aspects of the estimate that are very important. Once our estimating process had gotten to a more specific figure we took some of the focus off that number and put it on developing a range. While the estimate is important, the range of one's estimate is also a major part of the project. Different items can affect this range and the final costs that go into a project.

One of these factors is inflation. When making an estimate, one of the most important considerations is the current inflation rate and also the predicted inflation rate throughout the duration of the project. High inflation rates not only increase the cost of a project but can also affect

other parts of the project such as scheduling or purchasing packages. We observed a good example of this with the WPI residence hall. Issues came up with respect to the scheduling and the cost of the project. If the project's construction was delayed another year, how high would the inflation rates be then? And if the construction was pushed into fast track, how much would this affect the interest rates? These things were considered when finding the range of the cost.

When producing a range for our estimate, a few approaches were taken. Due to the fact that our group could not gather comprehensive references for a dormitory building, we were left to use figures and numbers from other types of buildings. After much consideration, it was suggested that using figures for both an office building and a motel could get a rough area to base our estimate range on. Using the total square feet of our proposed dorm building and our most recent total cost estimate, we figured the percent difference of the high and low ranges for both the office building and motel given by Project Management for Engineering and Construction (2000) by Garold D. Oberlender. By applying these ranges to our estimates for each component of our project, i.e. foundation, roofing, etc., we were able to form a relatively accurate range for each part of our project. Worksheets for both of these methods can be found in Appendix I.

5.0 Use of Building Information Model – REVIT

5.1 Introduction

The building information model is a very useful tool in both design and construction. There are many different building information model programs, for this project we used REVIT by Autodesk. This tool allows the user to create a three dimensional model from isometric views as well as assist in generating quick and accurate estimates based directly on the architectural/engineering drawings. This is done by creating schedules and/or quantity take-offs from the drawings which are useful for cost estimating. The use of this tool allows for quick and accurate estimates based on the architectural/engineering drawings.

5.2 Integration of REVIT in Construction Field

Technology over the years has improved greatly and the Architecture and Engineering industry (AE) has taken advantage of this. Many companies have had to streamline their organization and mode of operation so that they can “stay ahead of the game” and continue with competitive bidding. In order to do this, many companies have implemented new software for 3-D drawings. This would make the task of delivering their work would be more convenient, and efficient; as well as to improve their visual presentations.

Over the years the software companies that produce programs for 3-D modeling have had to improve upon their products so that they can accommodate the growing demands and needs of the dynamic AE industry. Examples of the new and improved design software are AutoCAD, Form Z, Solid Works, ArchiCAD, and Auto Desk REVIT, with Auto Desk REVIT as the most popular one.

As a design tool, the Auto Desk REVIT software is very easy to learn. The help option, software tutorial and the accompanying textbook are comparatively easier to understand and learn than most of the other design software available. Thus, in the design of the New Residence Hall for

the WPI community, REVIT was chosen over the other software options because of the numerous advantages associated with its use.

The different design options for the new residence hall were based on the design proposals, presented by the Architect (Cannon Design). The original designs were prepared through input from the WPI community, administration; site visits to the proposed location and some interaction by the use of surveys with the student body. Those original designs were narrowed down and modified based on input from the bi-weekly meetings during which the plans were presented. Simplified versions of these designs are drawn in the Auto Desk REVIT program for easier viewing and measuring. Examples of the REVIT drawings that this group prepared can be found in Appendix J. No permanent changes were made to the design in the program until the design was finalized but as plans were modified, the corrections were reflected in our design.

The REVIT model began with the drawing of the floor plan, which was created starting with the first floor. Initiating the design mode, which automatically activates the drawing tool, which happens to be the pencil, started this. The pencil tool acts as the essential drawing tool in this program. To draw a wall, for instance, one has to decide which type of wall, the wall thickness and the material of the wall. Depending on what lengths and widths one needs to draw to, the total length can be typed which will automatically snap it to that length or one can check the distance as and when one moves the pencil. With the first floor drawn, the repetitiveness and similarity of the following floors allowed for the next story to be drawn with ease and in less time. Because each of the entities drawn calls for a selection of a material, and the fact that the software has a library of materials to choose from, the software has the tool that would allow you to customize materials based on your need.

Sizes of elements, color, and specification can be chosen depending on the effect that one desires. For example, the stairs were customized and designed by changing parameters to suit the

needs, effects and aesthetics of the interiors. The difference in the floor heights also added to the need to customize those same stairs.

In order to add an element to the building, select 'basics' in the 'design bar' to the right of the screen and then simply select the element to be added. In the 'type selector' just above the 'design bar', you can choose the type of element to be added, i.e. Basic Wall: Exterior Brick of CMU's. The 'properties' button to the right of the 'type selector' can be used to edit the properties of the building element, such as size, material or floor level.

Another interesting option in the REVIT program is the flexibility of the viewing tools. The program allows a user the ability to look at different sides of the building, as well as easily create 3-D models. This option will ultimately help in the later choosing of certain elements of design. An example of this would be the size of doors and windows, which could be decided even before those elements were put in the design. A significant advantage that this 3-D viewing creates is that a user is able to determine whether or not the design is aesthetically appealing. Figure 11 shows Design Option E with some windows inserted in the building.

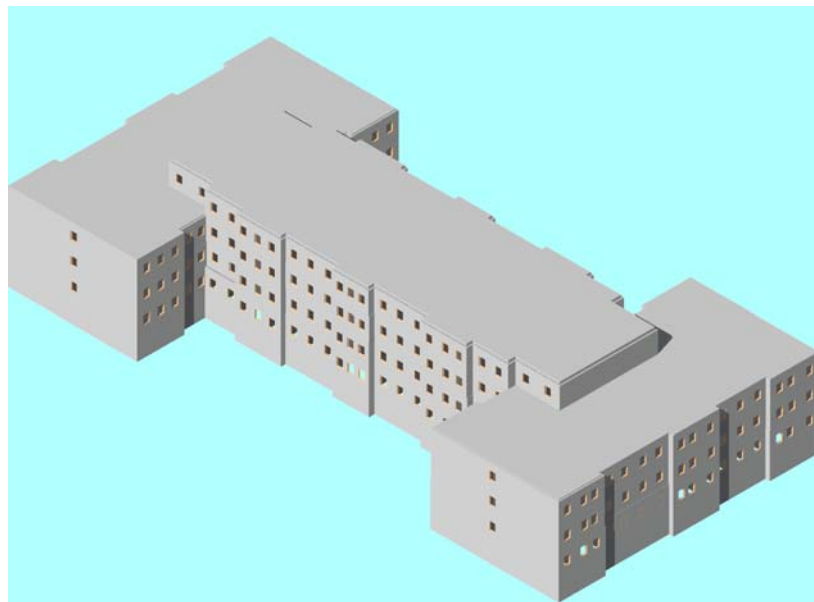


Figure 11 - Design Option E

One other interesting aspect of the software is that as and when these materials are chosen, it creates a database for the materials that have been used. These are then used for the cost estimating which becomes even easier as a result of the software's capabilities to incorporate RS Means cost data into the design's cost estimate.

Although Auto Desk REVIT produces many advantages and is very easy to work with, the software does have some limitations in its use. Older versions of the software cannot open files created with the new releases. This limits the efficiency in the use of the software because a user is limited in where and when they can access a file. While this is a disadvantage, it seems that the program does have significant advantages that surpass its shortcomings.

5.3 REVIT in Cost Estimating

In addition to its 3-D modeling capabilities, REVIT also has the ability to quantify and schedule all the elements of a building, based on their properties. This capability makes REVIT a very useful tool in the cost estimating of a building construction project. As a wall or door is added to the model drawings, the schedule is automatically updated in REVIT to reflect the change. Depending on the takeoff units for the building elements, fields representing the properties of the building elements can be specified in the REVIT schedules, which can then be exported to a script file. The script file, which opens as a file in the 'notebook' feature on any computer, can be converted into any type of file, i.e. Microsoft Excel or Microsoft Word. Once the script file has been created, you can choose to import it into Microsoft Excel and link it to a given workbook provided by Ken Stowe of REVIT. Once the files are properly linked, the excel workbook by Mr. Stowe, automatically calculates the amount of each building material based on the fields provided from REVIT¹⁵. From these calculated amounts, the cost of each quantity takeoff can be estimated and eventually a total cost can be found.

¹⁵ Handler, Laura

In order to convert a REVIT schedule to a script file, the user must first view the schedule in REVIT by selecting the 'Schedules/Quantities' tab located in the 'project browser'. Once the schedule is selected, look to the tool bar at the top left of the screen to find a 'file' option, highlight 'export' and select 'schedule'. REVIT will then create a script file of the schedule that is currently on the screen. Right click on the script file and select 'open with' > 'Microsoft Excel' and then save it as an Excel (.xls) file (see Appendix K for examples of script files). This will make the script file readable and more conducive to cost estimating. In addition to the workbook, Ken Stowe also provided an "import macro", this formats the excel schedules and quantifies the building elements based on their properties automatically. To do this, one should open the workbook and update the links for each takeoff with the corresponding Excel schedule from REVIT. Once the schedules from REVIT are linked to the workbook, the estimator can edit the worksheets with existing unit prices for the specific materials used in the construction project.

For this project we used the REVIT program to assist in the cost estimating of the proposed roofing systems for the WPI New Residence Hall. Once we had designed the beams and girders we loaded the necessary beam sections from a database in the REVIT program. To do this we selected to modeling option from the tool bar, highlighted "structural" and selected "beam". When this is done a menu at the top appears displaying the "family" of structural member being used, i.e. W-Wide Flange Beams. To the right there is a button labeled "load". Clicking on the "load" command opens the database in the program and there are several folders to choose from. Since we were using REVIT to produce a schedule for the structural steel we opened the "structural" folder selected W-Wide Flange Beams and loaded the proper beam sections into the REVIT file. WE obtained the unit price in dollars per linear foot (\$/lf) from RS Means and entered the values into the REVIT schedules. Once the schedules for the structural steel were created and opened in Microsoft Excel we proceeded with the cost estimating.

Although it is very easy to create a 3-D model of a building using REVIT, the process for linking the schedules produced in REVIT to a Microsoft Excel workbook is not a direct link. This requires the workbook provided by Ken Stowe to be updated, using the procedure explained above, as the drawings continue to be edited. The ability of the software to create takeoff schedules for a project can be very useful to the estimator once knowledge of the program and the process of exporting the schedules to script files have been learned. However, the software can only create a takeoff schedule based on the parameters provided by the user and can not be used to directly quantify or price the elements in project. This limitation of the REVIT software is the reason that the schedule produced in REVIT must first be exported to a program with these capabilities such as Excel.

6.0 Structural Design and Cost Comparison for Roof Systems

6.1 Introduction

As part of our MQP we are required to fulfill a capstone design relating to our project. For the WPI residence hall we decided to produce a conceptual design for the structural roof system. This task brought an interesting twist along with it by introducing the option of a green roof, along with the standard steel composite roofing option. A green roof is designed to accommodate additional soil and vegetation loads in order to create a recreational environment. To fulfill the capstone design requirements for our project we decided to design two different structural roof systems. The first was a composite steel system built according to Massachusetts building codes. The second was also a composite steel system; however it was designed to accommodate an addition of a green roof in the future.

6.2 LEEDS

One major aspect of the WPI residence hall was to be an environmentally friendly project. The Leadership in Energy and Environmental Design (LEED) is a rating system for green buildings. This system is broken into six categories, and includes sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design process¹⁶. These categories consist of a number of credits, each pertaining to a specific issue or standard which must be met to receive that credit. LEED certification levels are set to four different ranges of points. For a project to LEED certified a minimum of 26 points is required. Between 26 and 32 points provides the minimum LEED certification. A silver certification level is achieved when a project earns between 33 and 38 points while a gold level is between 39 and 51 points. Any

¹⁶ <http://www.rexelarchive.com/drupal-4.4.2/node/view/201>

project achieving 52 or more credit points is considered part of the platinum level¹⁷. This is the highest certification level with only an average of about three percent of all LEED certified projects achieving it.

Although a green roof option was not included in the original design it became a serious alternative for the RHPC to consider. There were several reasons supporting this addition, one of the biggest reasons being aesthetics. An issue with the building throughout the planning process has been the view of the roof from the upper campus. Other advantages of a green roof are the educational experiences and LEED benefits. However, with the addition of LEED accreditation brings along the possibility of an increase in cost. The additional costs linked to this option include but are not limited to soil, plants or seed, and maintenance. Any additional costs will stem from the need for larger and stronger beams which are required for the heavier loads.

6.3 Roof Design and Procedure

To design our first roof system (without the green roof) we started by calculating the tributary area. This was done using a beam spacing of five feet on center to acquire an area of 150 square feet. Using the appropriate dead loads, live loads, and snow loads we were able to determine the distributed load (W_u). Using a length of 36 feet as the greatest beam span we then calculated the design moment (M_u), which let us determine the plastic modulus (Z_x). We decided to try three different beam sizes for the roof joists: W10x33, W14x26, and W12x30. After adjusting for the weight of the beams, we determined that the W12X30 section would work best. For girders we chose W12x120, W18x86, and W14x109 sections, and determined that the W14x109 section would be the best choice for the roof system (See Appendix L for regular roof design worksheets).

After the design of the original steel roof system, we designed a second structural roof system. This second roof took into account the addition of a green roof to the building. This

¹⁷ <http://www.usgbc.org/DisplayPage.aspx?CategoryID=19>

addition changes the design loads for the roof which in turn changes the beam sizes needed to support the added weight. The joists needed in the green roof design came out to be a choice of W10x160, W12x53, W14x48 sections which are relatively the same depth but have a larger unit weight, and required girders of W14x193, W18x158, or W24x131, with the W18x158 being the best selection for the girder sections (See Appendix M for green roof design worksheets). Figure 12 shows the typical layout for the beams and girders for both roofing systems. Tables 5 and 6 are examples of the schedules created in and exported from Autodesk REVIT for the regular roof and green roof respectively.

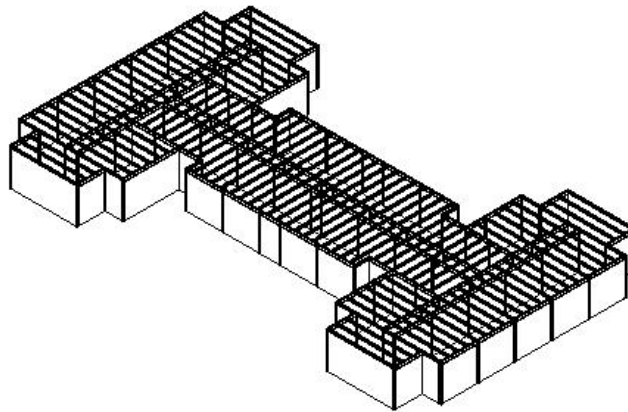


Figure 12 - Typical Roof Frame Layout

Structural Framing Schedule						
Cost	Family	Structural Usag	Type	Length (ft-in)	Length (ft)	Cost
111.05	W-Wide Flange	Girder	W18X158	30' - 0"	30	3331.50
111.05	W-Wide Flange	Girder	W18X158	30' - 0"	30	3331.50
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
111.05	W-Wide Flange	Girder	W18X158	20' - 0"	20	2221.00
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	36' - 0"	36	1333.80
37.05	W-Wide Flange	Joist	W12X53	25' - 0"	25	926.25
37.05	W-Wide Flange	Joist	W12X53	25' - 0"	25	926.25

Table 5 - Green Roof Structural Frame Schedule Example from REVIT

Structural Framing Schedule

Cost	Family	Structural Usage	Type	Length (ft-in)	Length (ft)	Cost
57.25	W-Wide Flange	Girder	W14X109	30' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	30' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
57.25	W-Wide Flange	Girder	W14X109	20' - 0"	20	1145.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	36' - 0"	36	756.00
21	W-Wide Flange	Joist	W12X30	25' - 0"	25	525.00
21	W-Wide Flange	Joist	W12X30	25' - 0"	25	525.00
21	W-Wide Flange	Joist	W12X30	25' - 0"	25	525.00
21	W-Wide Flange	Joist	W12X30	25' - 0"	25	525.00
21	W-Wide Flange	Joist	W12X30	25' - 0"	25	525.00

Table 6 - Regular Roof Framing Schedule example from REVIT

6.4 Cost Comparison

This additional steel has an effect on the final cost of the roof. With the decision to add a green roof to the residence hall, two major aspects of the project are changing. The first and many times most important part of the project is the overall cost. Different alternatives for the project are weighed versus their additional cost. In this case the green roof would add overall cost to the project but in return would make the building more environmentally friendly along with other alternative benefits such as the aesthetics.

Through our cost analysis of both roof systems using the design methods stated in section 6.3 we were able to produce two cost estimates. We calculated that for the basic structural steel roof system, the cost of structural steel totals about \$221,660. The cost of structural steel for the conceptual green roof design totaled about \$272,475, which is just over \$50,000 more than the basic roof. The additional soil to be used in the green roof would cost about \$52,304, making the total cost for a completed green roof almost \$324,000 (See Appendix N for regular roof material cost worksheets and Appendix O for green roof material cost worksheets).

6.5 Capstone Conclusions

The initiative taken by WPI to suggest a green roof shows much foresight and should be commended by all. This planning sets the foundation for many improvements and opportunities in the future. One such improvement is the impact that the green roof would have on the use of energy. By providing better insulation than a standard structural steel roof, the new residence hall would be more environmentally friendly while saving the university money on heating. If the outside air is over 25 degrees Celsius, the rooms under the green roof would potentially be 3-4 degrees Celsius cooler. This translates into about 10% reduction of the energy needed to cool or heat the rooms. The roof would also become home to butterflies and song birds, as well as a recreational place for

students to gather¹⁸. Along with additional benefits the green roof would lead to a higher number of points awarded for the LEEDs accreditation.

¹⁸ Cannon Design PowerPoint Presentation, 12/13/2006

7.0 Conclusions

Through the evolution of this project we have witnessed many changes and adaptations as new ideas and perspectives entered the realm of possibility. But these changes were simply necessary to reach an overall building design that would please all parties involved. The project began with some expectations that were not met and/or were changed early along in the process. The largest being the scale of the building which was changed due to a change in the needs of the university which ultimately involved budget limitations.

In the end the building was decided to be apartment style living with a mix of double and single bedrooms, each outfitted with their own kitchen. The building will house approximately 232 students, which has greatly changed since the beginning of the project where it was projected to house at least 300 students. There will also be a separated two level parking garage that will hold 150 cars. The roof will be a composite structural steel system, but the building itself will be built to withstand loads for a green roof which could be added in the future.

While using different methods to estimate the building throughout this design process, our group has found that the traditional take-off method is accurate and easy to use. However, using REVIT as an additional tool was helpful to keep track of the changes in design and make the adjustments easier. Saving each drawing made in REVIT as a different file was also helpful in the estimating for comparison reasons. You are able to bring up multiple schemes of the building to not only mathematically compare but also visually make comparisons.

Designing the building for possible additional loading of a green roof was an excellent way to save money in the future. The university now has the choice to make this environmentally friendly addition later, if wanted, without having to reinforce the steel structure which could be more costly than preparing ahead now. Along with the cost savings, the planning for the green roof could

bring the building closer to a higher LEED accreditation level, savings on heating costs, and additional space for students to congregate.

It was clear in the beginning of this project that WPI was in need of this additional building. However, it the design has exceeded their original expectations with the addition of a higher level of LEED accreditation, a green roof and an ultimately an attractive building with the smallest footprint possible. WPI, Cannon Design and Gilbane Building Co. should be praised for their hard work and dedication for coming up with the optimum building design which is documented in this paper. The final design layout plus an aerial picture with the building superimposed can be viewed in Appendix P.

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Appendices

Appendix A Survey

WPI is considering building new residence halls to meet the needs of our undergraduate students and we need the help of our **current residents as well as those of you who reside off campus**. We are currently in the process of determining what types of residence facilities students would desire the most and what amenities they would see as essential for future residence halls.

We want to know what will attract those of you who currently reside in the halls into staying on campus. We also want to know why many of our upper-class students chose to move off campus and what, if anything would attract them back to on-campus housing.

Please take 10 minutes of your time to complete the attached on-line survey. Your feedback will help WPI to enhance the quality of life for current and future students and will insure that the housing we build will be state-of-the-art and will meet your needs. To thank you for taking the time to complete our survey, we will be randomly selecting 5 students to receive Best Buy gift cards in denominations of \$25 -\$100.

Survey

- 1) Your Class Year:
 - 2004
 - 2005
 - 2006
 - 2007
 - 2008
 - Other

- 2) Your Sex:
 - Male
 - Female

- 3) What US state or country are you from?

- 4) Do you currently have a car at WPI?
 - Yes
 - No

- 5) Where do you currently reside?
 - Founders Hall
 - Ellsworth/Fuller Apartment
 - Other WPI residence hall
 - Off campus apartment/house/room (not with parents)
 - WPI fraternity/sorority house
 - Live at parents' home and commute to WPI

- 6) Have you attended a Project Center as of this date?
 - Yes
 - No

If you currently live in a WPI residence hall, skip to question # 13

- 7) If you do not currently live on campus and do not commute from your parents' home, what is your monthly rent per person including utilities?
 - Less than \$300
 - \$301-400
 - \$401-500
 - \$501-600
 - \$601-700
 - \$701-800
 - more than \$800

8) How many roommates do you have?

- 0
- 1-2
- 3-4
- 5 or more

9) Do you have a single bedroom?

- Yes
- No

10) How did you find your current housing?

- WPI on-line listing service
- Other

11) If you lived at one time in a WPI residence hall, please identify the top reasons you had for moving off campus. **Please select up to 3 choices from the following list of responses**

- I didn't get a good number in the housing lottery
- I wanted to live in my chapter's fraternity/sorority house
- Residence halls are too noisy
- No on-campus housing was available when I transferred here
- I wanted a single bedroom
- I didn't like the dining hall food
- It was cheaper to live off campus
- I did not want to be on a meal plan
- I couldn't get an Ellsworth/Fuller apartment
- I couldn't get a suite in Founders Hall
- I didn't like residence hall rules
- I wanted to live with non-WPI roommates
- I wanted a private bathroom

12) What statement best reflects your position? **(Please choose only 1)**

- I would move back on campus if WPI built the kind of housing that I desire.
- I would move back on campus if there could be guaranteed housing for upper-class students.
- I would not move back on campus regardless of what WPI builds.

We would like to understand from all of our students what is most important to you in your housing. Please think about what your ideal residence would look like and answer the following questions:

13) Rank the following residence hall attributes based on their importance to you, on a scale of 1 to 5, with 5 being very important, and 1 being not very important.

- | | | | | | |
|----------------------------|---|---|---|---|---|
| Proximity to classes | 1 | 2 | 3 | 4 | 5 |
| Size of room/apt. | | | | | |
| Network access | | | | | |
| Single bedrooms | | | | | |
| Cost | | | | | |
| Utilities included in rent | | | | | |
| Security | | | | | |
| Kitchen facilities | | | | | |

Availability over the summer months

14) Rank the following residence hall amenities in order of importance to you, on a scale of 1 to 5, with 5 being most important, and 1 being not very important.

Furnished rooms/apartment	1	2	3	4	5
On site parking					
Air conditioning					
Phone/cable/network included in rent					
Laundry facilities within the building					
Common study/project team meeting space with AV equipment within the facility					
Fitness room in building					

15) Rank each of the following on campus housing options on a scale of 1 to 5, with 5 being the most desirable to you and 1 being the least desirable.

Traditional residence hall (single or double bedrooms, no kitchen, community bath)	1	2	3	4	5
Suite style residence (a mix of single and double bedrooms, shared living room and bathroom, no kitchen for up to 4 residents)					
Apartment (a mix of single and double bedrooms, shared living room, bathroom and kitchen for up to 4 residents)					

16) Part of the success of a residence hall is also based on the mix of students in the facility. Please **check all of the responses below that apply** to your beliefs:

Freshmen should be housed in traditional residence halls, such as Daniels, Morgan, Riley and Institute Halls, which promote community

Freshmen residence hall rooms should have private or semi-private bathrooms

Freshmen and upper-class students should be housed in the same facilities so that upper-class students can serve as role models and advisors to the freshmen

Sophomores, juniors and seniors should have equal access to all upper-class housing units

Seniors should be housed with graduate students in their own facility

Students should be allowed to sign-up to live in the same room each year without having to enter a lottery

Classroom/project space should be included in each residence hall to create a 'living/learning' environment

Faculty apartments should be included in the design of new residence halls

New residence halls should have a variety of styles, mixing apartments, suites, and traditional rooms (singles or doubles) together within a single facility

At least part of each freshmen and/or upper-class residence hall should be arranged as common Interest Housing for those students who want to live with others around a single theme such as foreign language, entrepreneurship, computer gaming, etc.

Other _____

Thank you for your participation. The survey results will be printed in Tech News and will be discussed at an open meeting in C term. Watch Tech News for the date, time and location.

If you wish to be entered into the raffle for the Best Buy Gift Cards, please include your name and email address below (optional).

Name:

Email:

Currently WPI houses 1241 undergraduate students in on-campus residence halls. Only first year students are guaranteed housing. Because demand exceeds supply, upper-class students participate in a housing lottery to secure housing past the first year. The remainder of the students not receiving on-campus assignments live in off-campus apartments or rooms, in Greek housing not owned by the University, or commute from their family home.

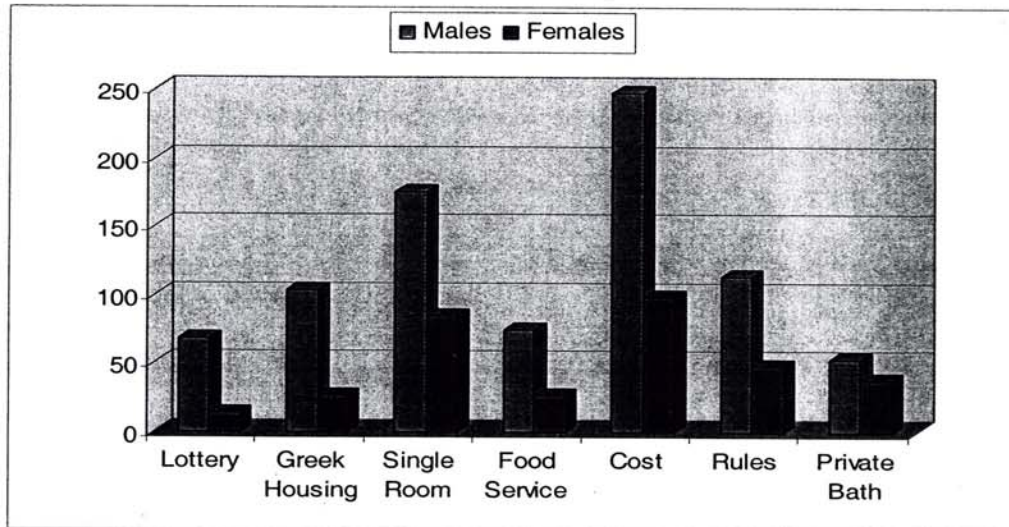
WPI seeks to understand if there is an unmet need for additional on-campus housing. On November 29, 2004, an electronic survey was administered to 2813 undergraduate students. Of that group, 1081 undergraduate students or 38% of the students returned the survey. The cohort was comprised of 323 females and 758 males. Of that group, 362 students live off campus, 26 live with their parents, 114 live in Greek housing and 578 live on campus. 1 student did not report a residence.

Students were asked 16 questions to determine their feelings about current residence hall options as well as what future options should look like. Specific questions targeted those students currently living off campus to learn what, if anything would attract them back to campus.

What are your top reasons for moving off campus?

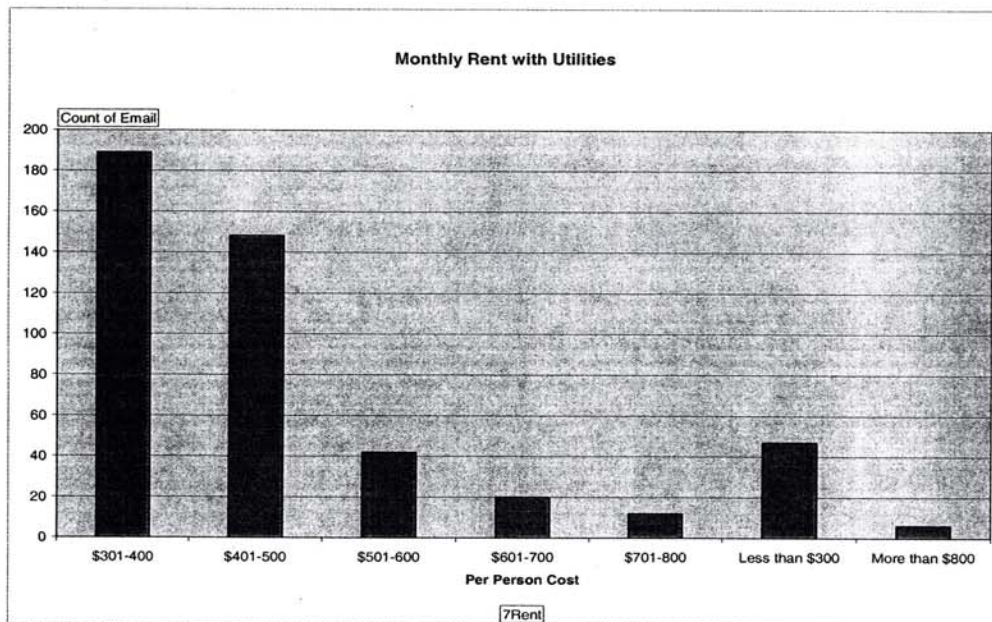
Twelve possible reasons were suggested for why students might have moved off campus after having lived for some period of time in a WPI residence hall. The top eight reasons are documented below. Students most often cited the lower cost of off campus apartment living as compared to residence hall living as the primary reason for leaving campus housing. The second most frequent response was the desire to have a single room followed by a dislike for rules associated with University housing. The top five responses were consistent across genders.

	Males	Females	Total
Cost	247	99	346
Single Room	176	84	260
Rules	114	48	162
Greek Housing	103	27	130
Food Service	74	26	100
Private Bathroom	53	38	91
Lottery	68	14	82



What is your current off campus expense for rent and utilities?

Since students seemed to be sensitive to price, only those students currently residing off campus were asked to report what they were currently paying on a monthly basis for their rent, including utilities. The following chart shows the results.

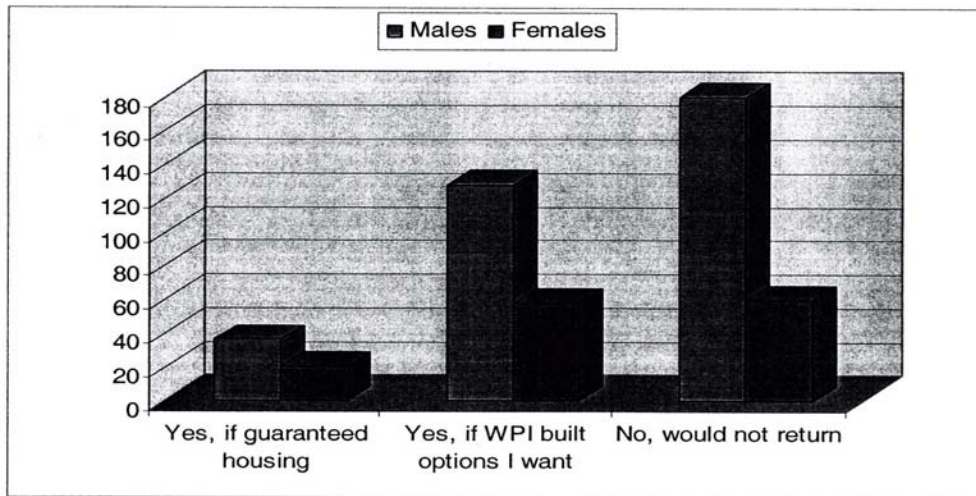


Consistent with a survey administered last year to graduate students, most of our off-campus undergraduate students are finding housing under \$500 per person per month including utilities. Although the accommodations may not be of quality, students are price sensitive and seek to find accommodations under \$400/month if possible and rarely over \$500/month.

Would you return to on-campus housing?

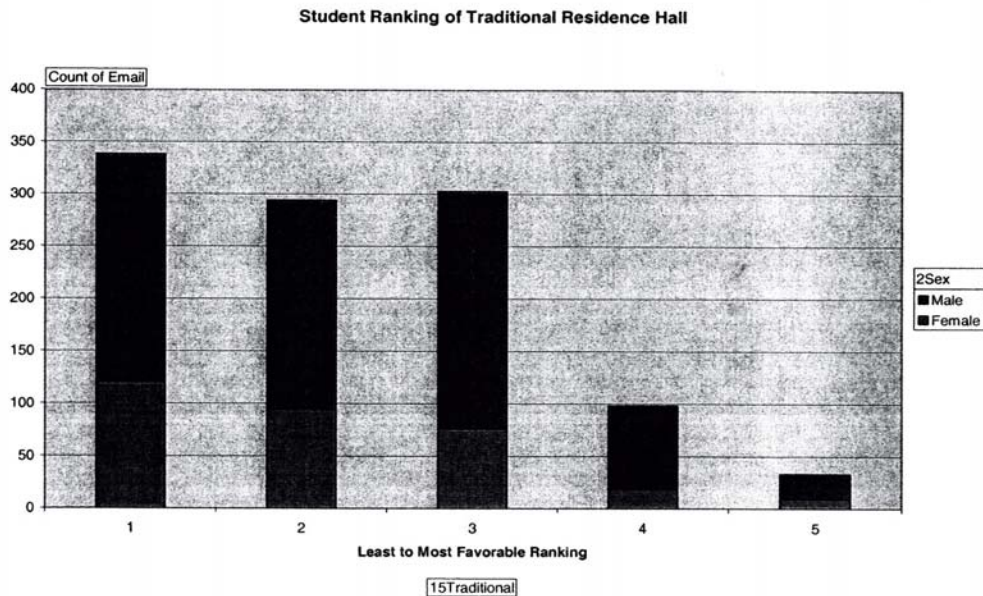
Only those students currently living off campus were asked to indicate if, and under what circumstances, they might return to University housing. While half of the students showed no interest in returning to on-campus housing, the remaining half indicated a desire to return if enough housing was constructed that would guarantee housing to students beyond the freshman year and if attractive housing options were built to include suite and apartment style residences.

	Males	Females	Total
Yes, if guaranteed housing	36	20	56
Yes, if WPI built options I want	128	58	186
No, I would not return	180	60	240

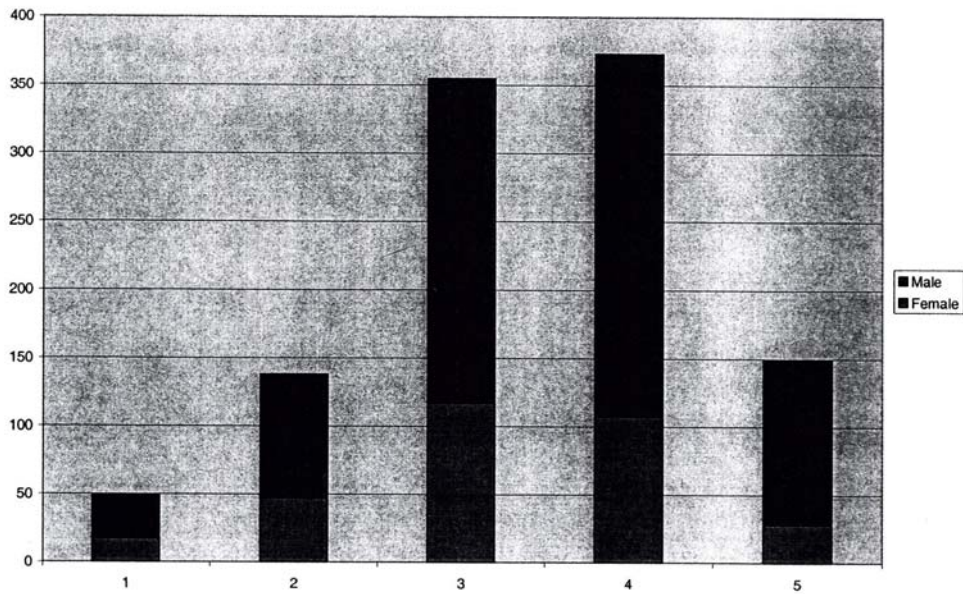


What housing options are most desirable to you?

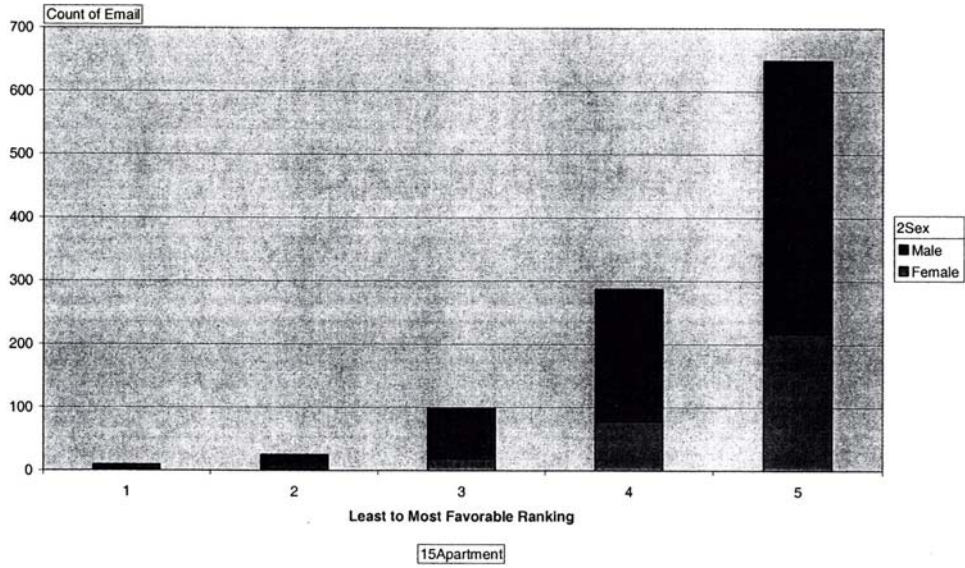
Students were asked to rank three residence hall types: **traditional halls**, with single or double rooms, no kitchens, and community bathrooms; **suite style residences**, with a mix of single and double bedrooms, shared living room and bathroom, no kitchen, for up to 4 residents; and finally **apartment style residences** with a mix of single and double bedrooms, shared living room, bathroom and kitchen for up to 4 residents. The scale used below is 1 to 5, with 5 being the most desirable option and 1 being the least desirable.



Student Ranking of Suite Style Residence Hall



Student Ranking of Apartment Style Residence Hall

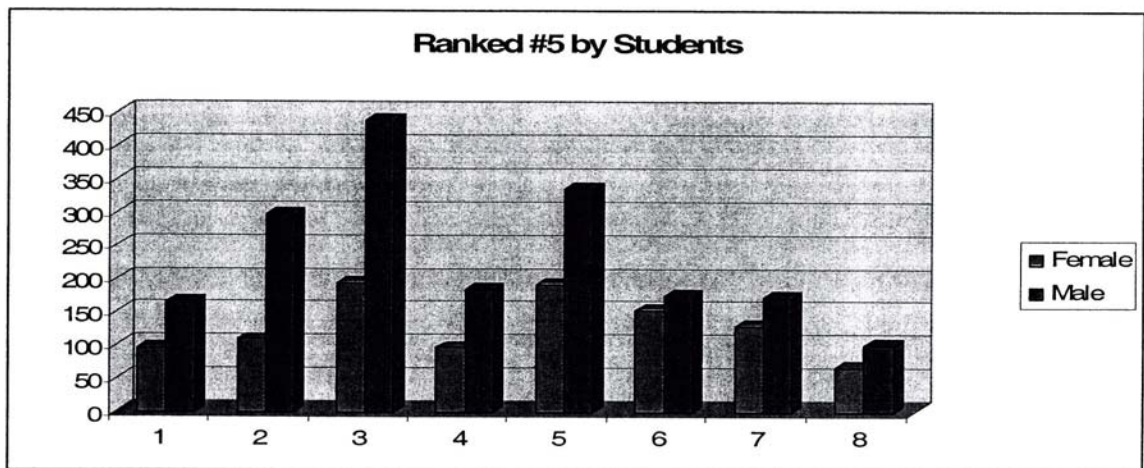


Students overwhelmingly identified apartment style residence halls as their first choice followed by suite style residences. There was very little interest in traditional residence halls with community bathrooms, double rooms and limited facilities. There was strong interest (well over 600 students) across the genders for apartments with up to 4 residents sharing a kitchen, living room and bathroom, with a combination of single and double bedrooms within the apartment.

What are the most important amenities and attributes in your residence?

Not only is the style of the residence hall important to its success in attracting students, but the amenities that it offers can mark the difference between a successful facility or a building with many vacancies. 17 different features were identified for students to rank in order of importance to them. Students were asked to rank the various amenities and attributes on a scale of 1 to 5 with 5 being the most important, and 1 being the least important to them. The following are the #5 rankings by gender of important attributes:

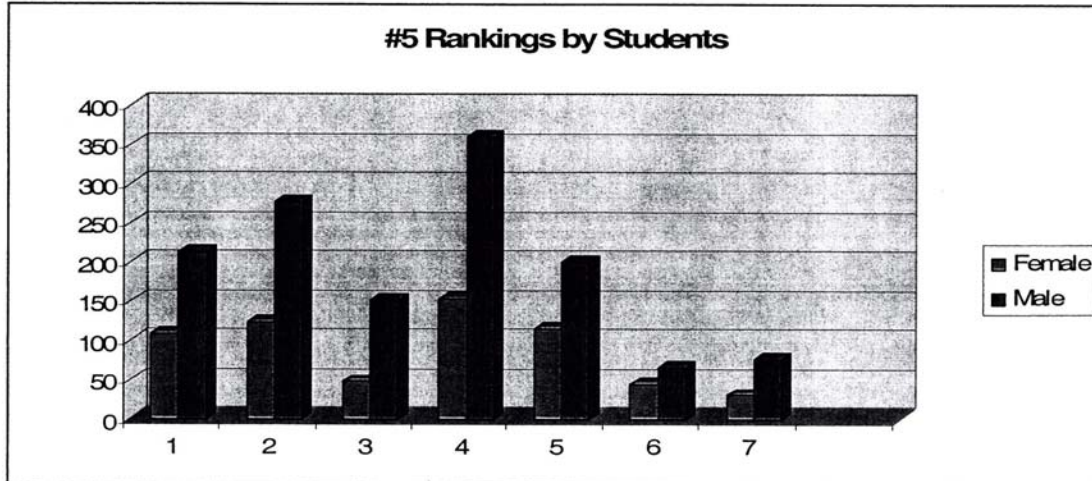
		Female	Male
1	Proximity	95	165
2	Size	109	297
3	Network Access	194	439
4	Single	97	185
5	Cost	191	334
6	Safety & Security	153	174
7	Kitchen Facilities	130	172
	Summer		
8	Availability	68	101



Students were most adamant that residence halls must have network access for all residents which is consistent with all current residence hall facilities and is a commodity that we can offer that the off-campus housing market cannot. Students were also extremely sensitive to cost. We will have to offer high value to cost for the facilities that we offer to students to compete with the cheaper but less valued off campus units. The top three attributes for women were network access, cost and security while for men they were network access, cost and size of the facility. Summer availability was least important for both genders.

The #5 rankings for most important amenities by gender are:

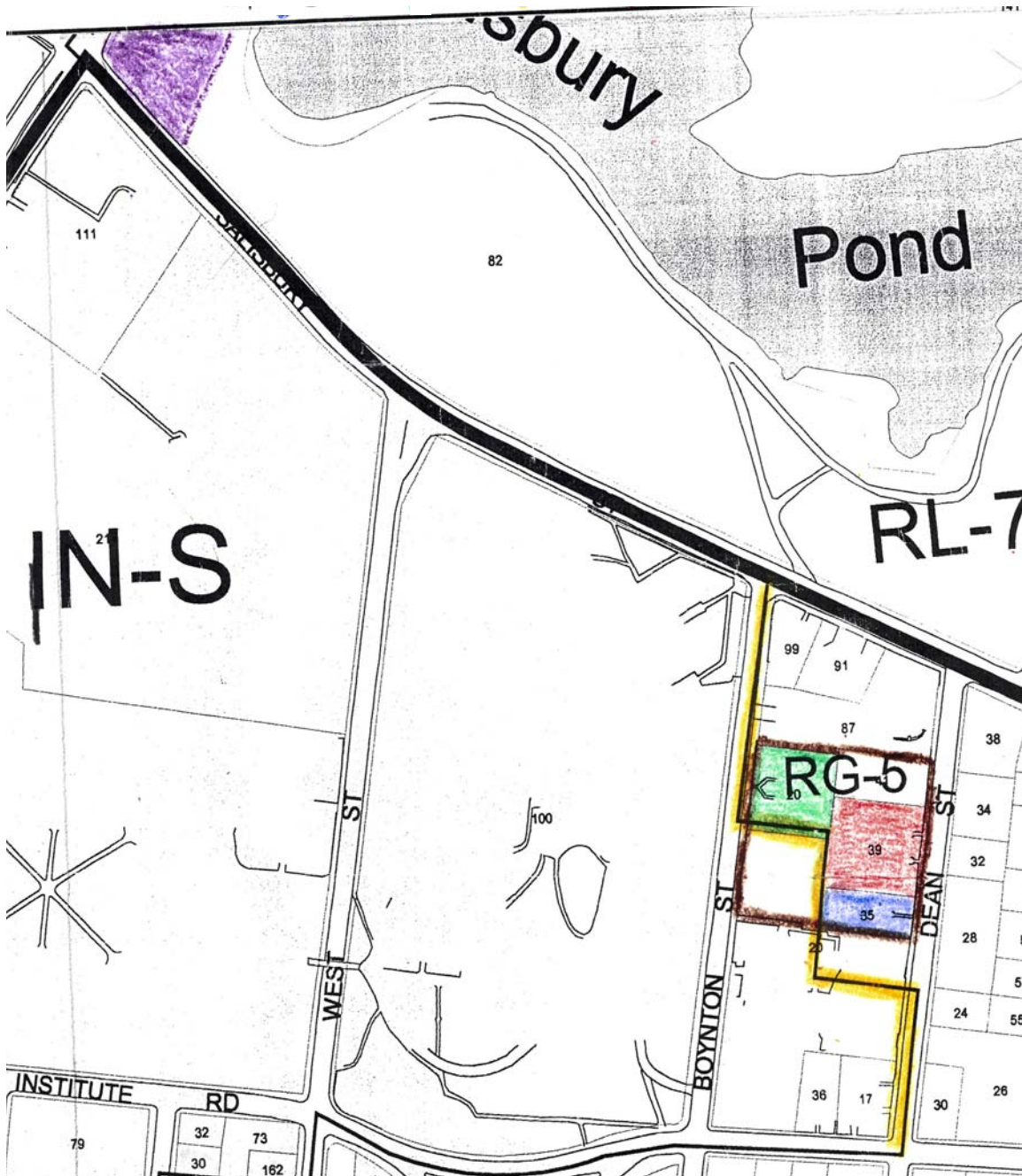
		Female	Male
1	Furnished	108	213
2	Onsite Parking	123	276
3	Air Conditioned	48	152
4	Network/Cable/Phone	153	359
5	Laundry Facility	114	200
6	Study/Project Facilities	44	67
7	Fitness Facilities	31	77



bathroom and living facilities. Facilities should be furnished, have onsite laundry facilities, card access locking systems, wireless network access, and some common space for study/project work or recreation.

Cost will be an extremely important consideration in the success of new residence facilities. Additional study needs to occur to understand the price-point for students and their parents for state of the art residence facilities. We must include both groups in the next phase of our study.

Appendix B Map of Proposed Site



- Legend**
- 35 Dean St. (campus police)
 - Salisbury Estates
 - 30-32 Boynton St (apartments)
 - City Zoning Lines (below is residential)
 - 31 Dean St (Graduate admissions, WPI Bio Eng. Institute, Administrative services)
 - Proposed site of building

Appendix C Project Schedule Differences

- **Original Conceptual Design Deadline was met.**
- **CM Engaged**

Cannon	Gilbane
8/25/06	Early October

- **Acquiring Property**

Cannon	Gilbane	Gilbane(2)
7/10/06-9/29/06	11/1/06-11/30/06	11/1/06-12/29/06

- **Provide Notice to Tenants**

Cannon	Gilbane
10/9/06-10/13/06	11/1/06-11/30/06

- **Vacate Properties**

Cannon	Gilbane
12/1/06-1/29/07	2/7/07-3/6/07

- **Pre Permitting**

Cannon	Gilbane
9/11/06-10/6/06	1/15/07-3/12/07

- **Schematic Design Phase**

Cannon	Gilbane
11/2/06-12/25/06	1/15/07-2/9/07

- **Design Development Phase**

Cannon	Gilbane
12/26/06-2/26/07	4/16/07-5/11/07

- **Steel Packages**

Cannon
2/20/07-4/2/07

Gilbane
5/2/07-5/29/07

- **Overall Construction**

Cannon
10/9/06-7/25/08

Gilbane
5/30/07-7/24/08

Appendix D Phase One: Structure Estimating Worksheets & Rendered Drawings

<u>Storey</u>				
1	"C" Shape			
	A=	35,400		
	Avg. Price	\$139.63		
	Subtotal:	\$4,942,902.00		
2	"I" Shape			
	A=	23,700		
	Avg. Price	\$145.59		
	Subtotal:	\$3,450,483.00	Preliminary Subtotal:	\$22,875,033.00
3	"I" Shape			
	A=	23,700		
	Avg. Price	\$145.59		
	Subtotal:	\$3,450,483.00		
4	"I" Shape			
	A=	23,700		
	Avg. Price	\$155.15		
	Subtotal:	\$3,677,055.00		
5	"I" Shape			
	A=	23,700		
	Avg. Price	\$155.15		
	Subtotal:	\$3,677,055.00		
6	"I" Shape			
	A=	23,700		
	Avg. Price	\$155.15		
	Subtotal:	\$3,677,055.00		

Scheme One, Method One

South Side

6 Storeys
12,000 SF
141.78 Avg. Price

\$10,208,160.00 Total

East Side

Preliminary Total

\$23,416,232.00

1 Storeys
13,225 SF
154.7 Avg. Price

\$2,045,907.50 Total

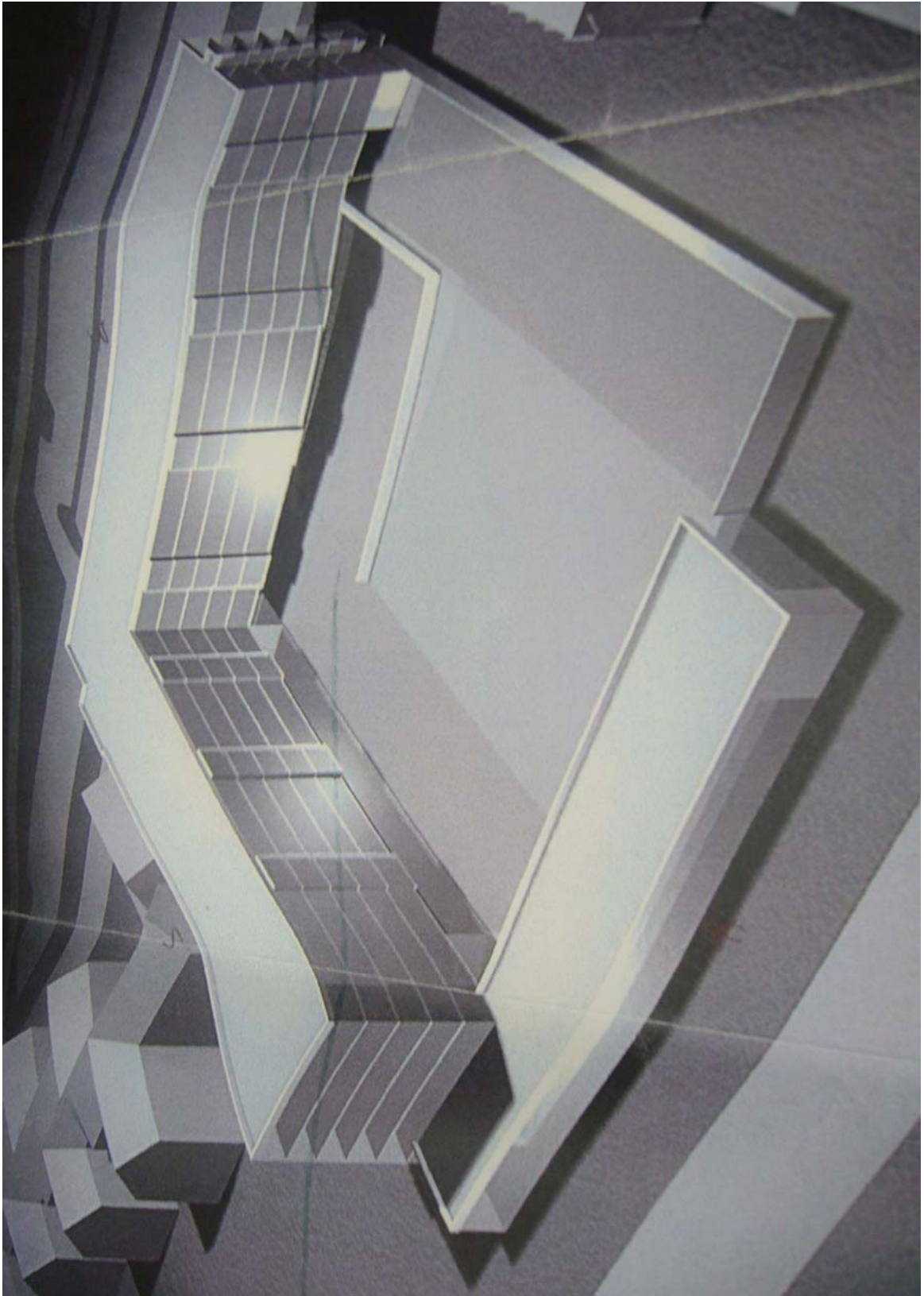
West Side

6 Storeys
13,225 SF
140.67 Avg. Price

\$11,162,164.50 Total

Scheme One, Method Two

Scheme One



Storey:

1	"C" Shape			
	A=	35,400		
	Avg. Price	\$139.63		
	Subtotal:	\$4,942,902.00		
2	"C" Shape			
	A=	35,400		
	Avg. Price	\$139.63		
	Subtotal:	\$4,942,902.00	Preliminary Subtotal:	\$20,690,397.00
3	"I" Shape			
	A=	23,700		
	Avg. Price	\$145.59		
	Subtotal:	\$3,450,483.00		
4	"I" Shape			
	A=	23,700		
	Avg. Price	\$155.15		
	Subtotal:	\$3,677,055.00		
5	"I" Shape			
	A=	23,700		
	Avg. Price	\$155.15		
	Subtotal:	\$3,677,055.00		

Scheme Two, Method One

South Side

5 Storeys
12,000 SF
143.89 Avg. Price

\$8,633,400.00 Total

East Side

2 Storeys
13,225 SF
143.93 Avg. Price

Preliminary Total

\$21,880,353.50

\$3,806,948.50 Total

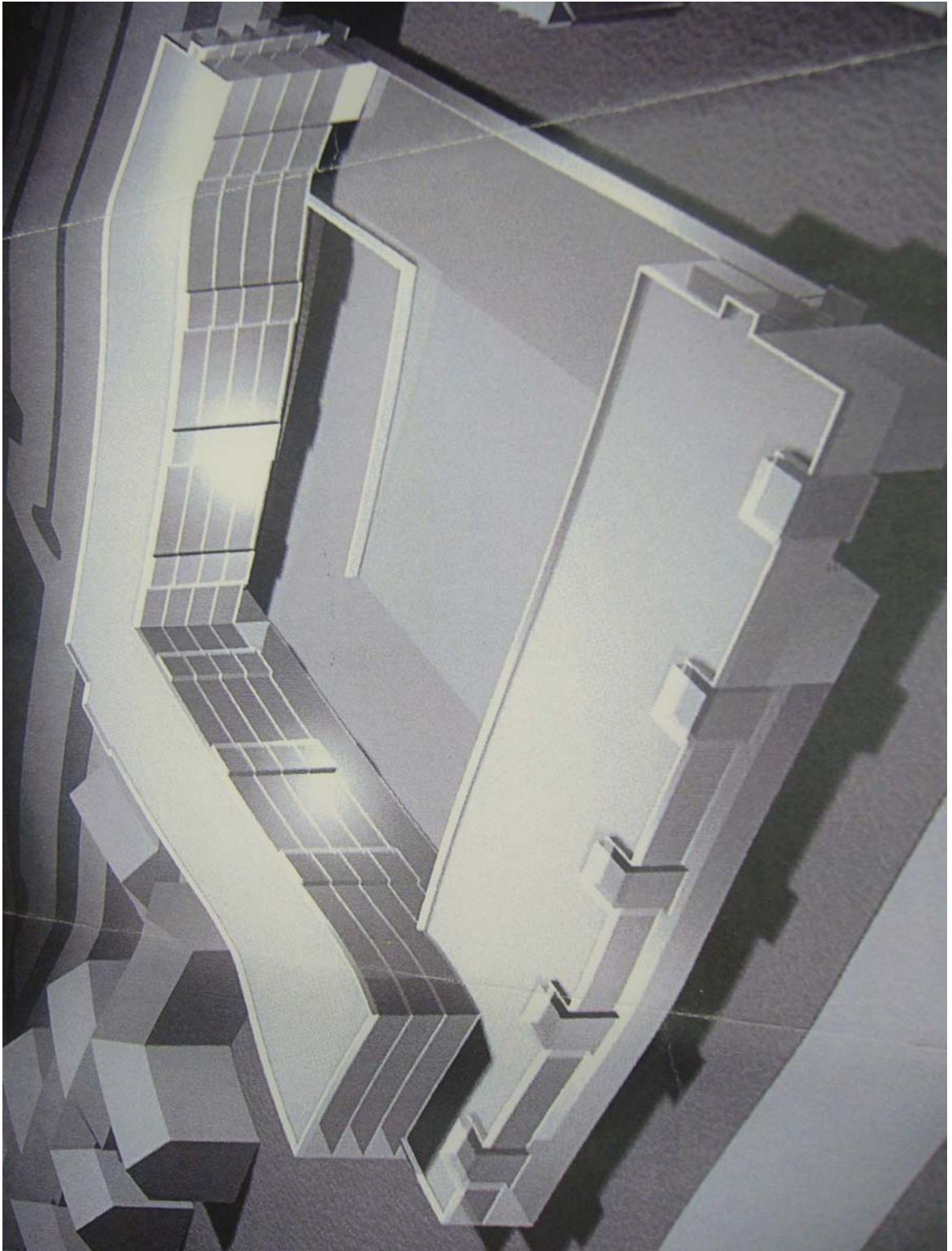
West Side

5 Storeys
13,225 SF
142.76 Avg. Price

\$9,440,005.00 Total

Scheme Two, Method Two

Scheme Two



Storey:

1	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
2	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00	Preliminary Subtotal:	\$21,282,638.25
3	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
4	" $\bar{\text{C}}$ " Shape			
	A=	13,225		
	Avg. Price	162.67		
	Subtotal:	\$2,151,310.75		
5	" $\bar{\text{C}}$ " Shape			
	A=	13,225		
	Avg. Price	162.67		
	Subtotal:	\$2,151,310.75		
6	" $\bar{\text{C}}$ " Shape			
	A=	13,225		
	Avg. Price	162.67		
	Subtotal:	\$2,151,310.75		

Scheme Three, Method One

South Side

3 Storeys
12,000 SF
139.39 Avg. Price

\$5,018,040.00 Total

East Side

3 Storeys
13,225 SF
137.98 Avg. Price

\$5,474,356.50 Total

Preliminary Total

\$21,654,561.00

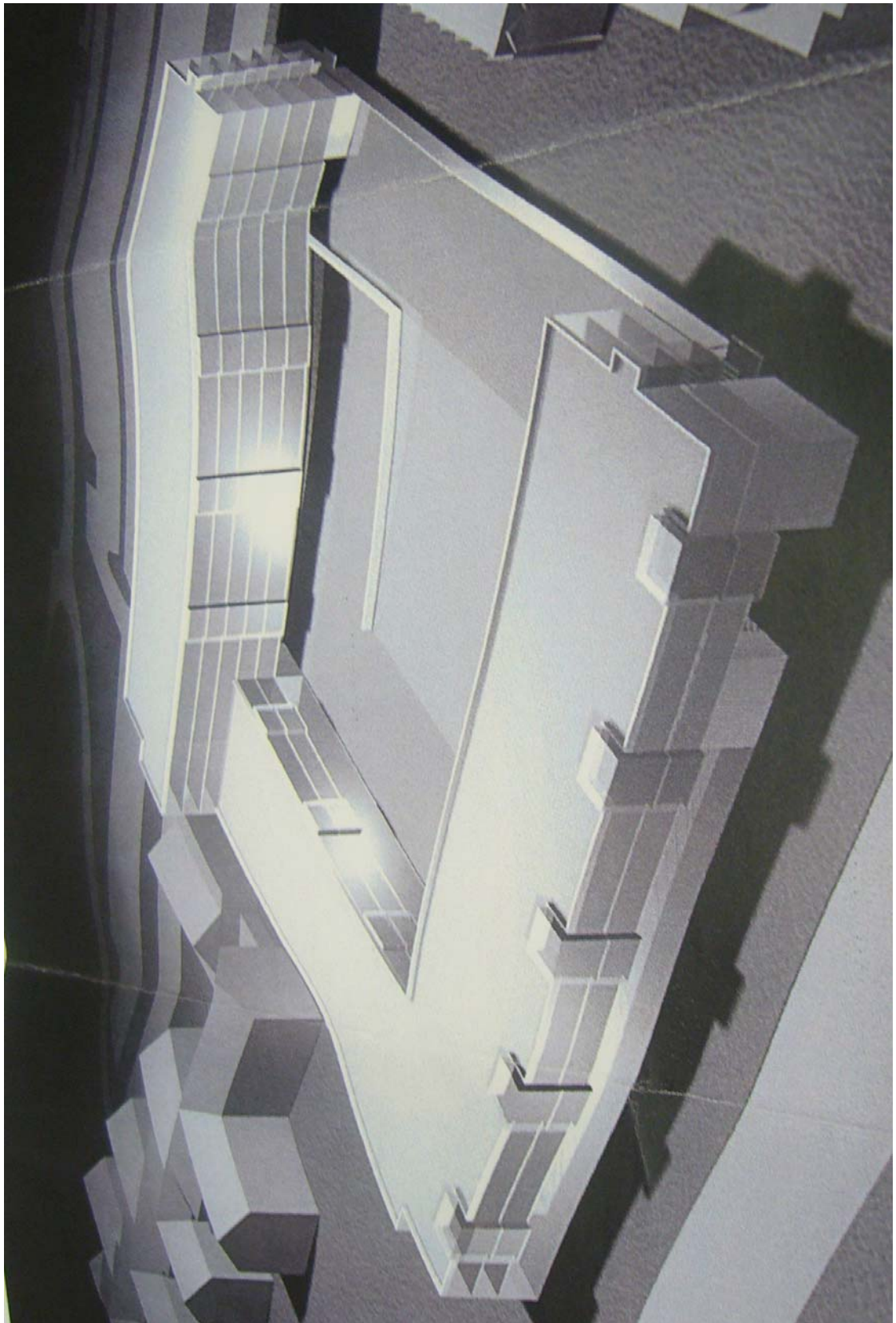
West Side

6 Storeys
13,225 SF
140.67 Avg. Price

\$11,162,164.50 Total

Scheme Three, Method Two

Scheme Three



Storey:

1	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
2	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00	Preliminary Subtotal:	\$20,657,071.75
3	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
4	"I" Shape			
	A=	23,700		
	Avg. Price	155.15		
	Subtotal:	\$3,677,055.00		
5	"L" Shape			
	A=	13,225		
	Avg. Price	162.67		
	Subtotal:	\$2,151,310.75		

Scheme Four, Method One

South Side

4 Storeys
12,000 SF
146.52 Avg. Price

\$7,032,960.00 Total

East Side

3 Storeys
13,225 SF
137.98 Avg. Price

\$5,474,356.50 Total

Preliminary Total \$21,947,321.50

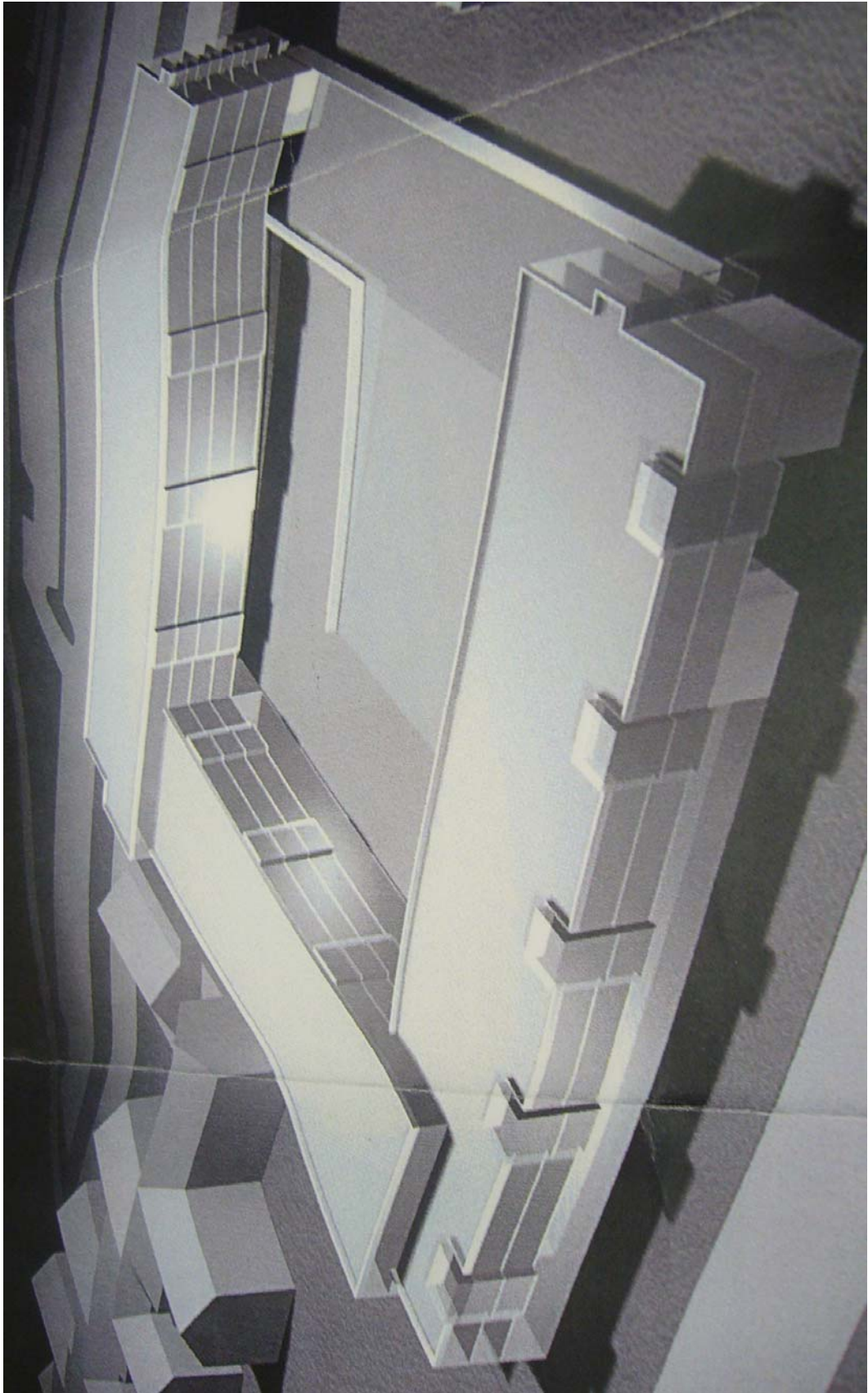
West Side

5 Storeys
13,225 SF
142.76 Avg. Price

\$9,440,005.00 Total

Scheme Four, Method Two

Scheme Four



<u>Storey:</u>				
1	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
2	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00	Preliminary Subtotal:	\$22,440,561.00
3	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
4	"I" Shape			
	A=	23,700		
	Avg. Price	155.15		
	Subtotal:	\$3,677,055.00		
5	"I" Shape			
	A=	12,000		
	Avg. Price	163.95		
	Subtotal:	\$1,967,400.00		
6	"I" Shape			
	A=	12,000		
	Avg. Price	163.95		
	Subtotal:	\$1,967,400.00		

Scheme Five, Method One

South Side

6 Storeys
12,000 SF
141.78 Avg. Price

\$10,208,160.00 Total

East Side

3 Storeys
13,225 SF
137.98 Avg. Price

Preliminary Total

\$23,372,589.50

\$5,474,356.50 Total

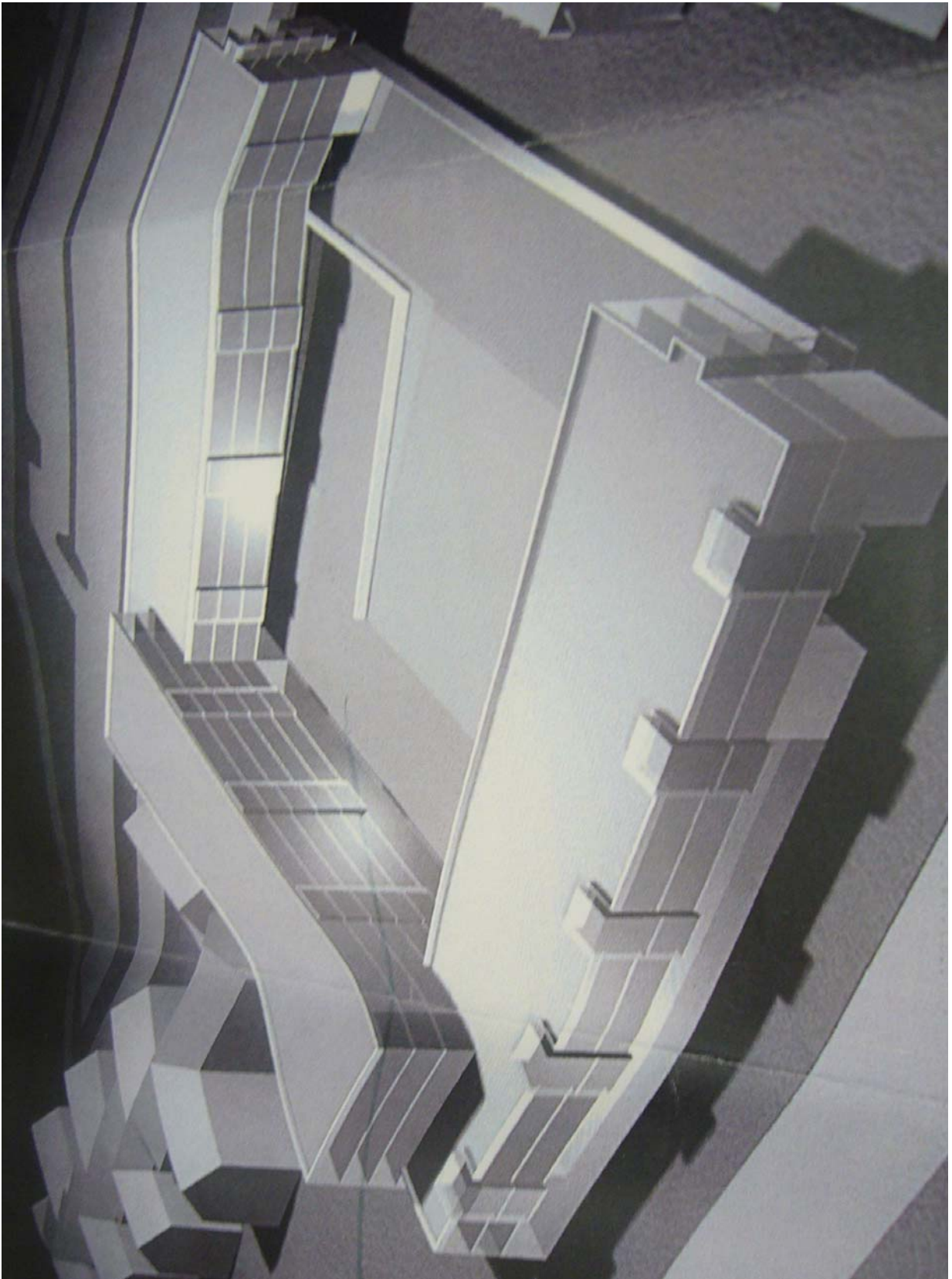
West Side

4 Storeys
13,225 SF
145.37 Avg. Price

\$7,690,073.00 Total

Scheme Five, Method Two

Scheme Five



<u>Storey</u>				
1	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
2	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00	Preliminary Subtotal:	\$20,145,078.00
3	"C" Shape			
	A=	35,400		
	Avg. Price	139.63		
	Subtotal:	\$4,942,902.00		
4	"C" Shape			
	A=	35,400		
	Avg. Price	150.18		
	Subtotal:	\$5,316,372.00		

Scheme Six, Method One

South Side

4 Storeys
12,000 SF
146.52 Avg. Price

\$7,032,960.00 Total

East Side

4 Storeys
13,225 SF
145.37 Avg. Price

Preliminary Total

\$22,413,106.00

\$7,690,073.00 Total

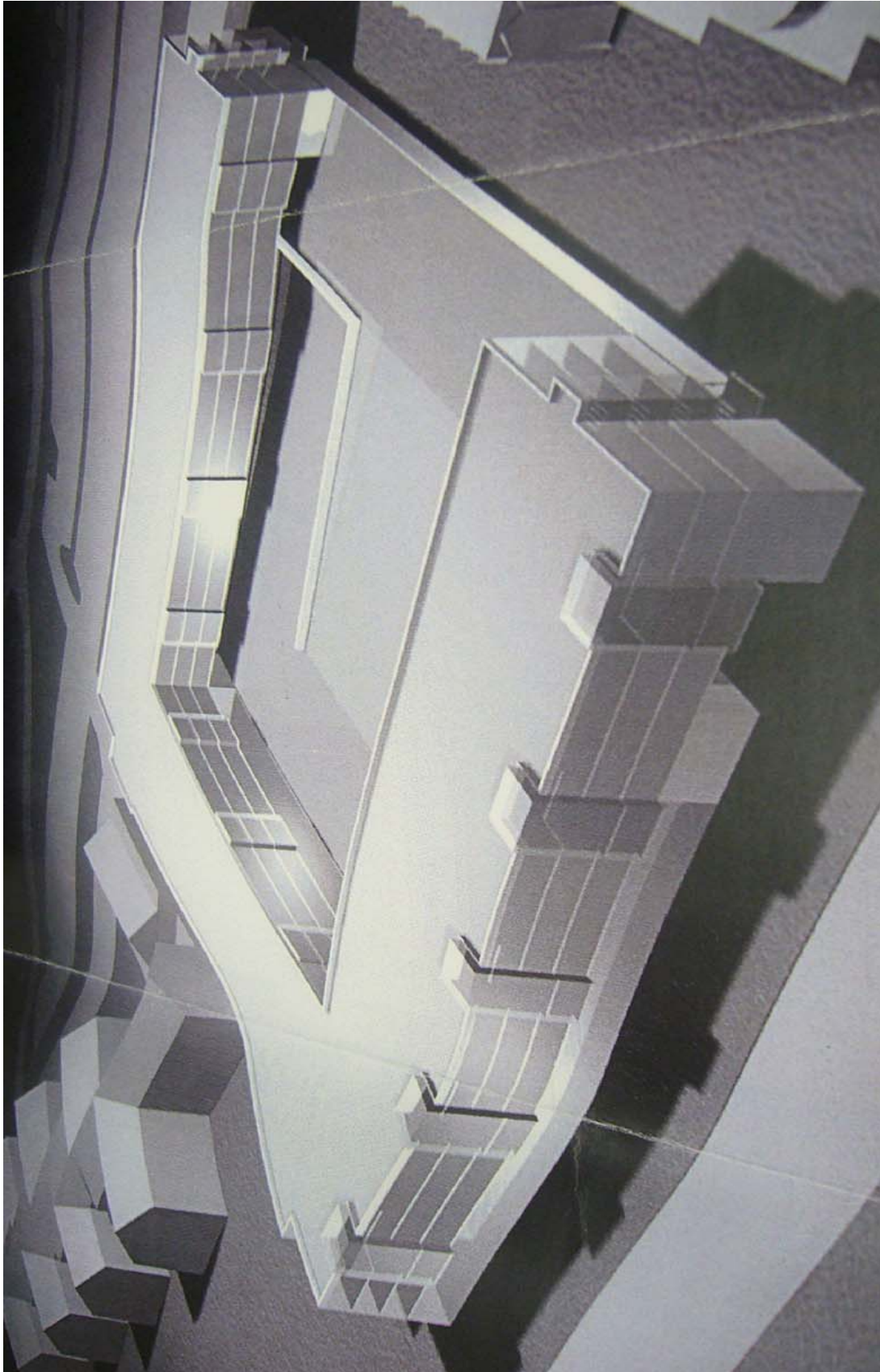
West Side

4 Storeys
13,225 SF
145.37 Avg. Price

\$7,690,073.00 Total

Scheme Six, Method Two

Scheme Six



Appendix E Phase One: Parking Estimating Worksheets

Above ground parking

space size (6x18) = 128 sq.ft	cost/sq. ft. \$2.50	cost for 200 spaces at ground level \$64,000.00	cost for 300 spaces at ground level \$96,000.00
----------------------------------	------------------------	---	---

Area	50000	63860	75000
Cost/sq.ft.	\$41.80	\$41.00	\$40.00

total cost of 2 story garage with inflation= \$4,167,428.06

Above Ground Cost Estimating Worksheet

Underground garage~ proposed garage to be 63,860 sq. ft

Area (sq.ft.)	30000	31930	40000
Cost/sq.ft. (\$)	\$44.35	\$43.34	\$43.10
total cost/floor of garage	\$1,330,500.00	\$1,383,846.20	\$1,724,000.00
cost for 2 story garage	\$2,661,000.00	\$2,767,692.40	\$3,448,000.00

total cost of underground garage with inflation= \$4,405,276.39

Underground Cost Estimating Worksheet

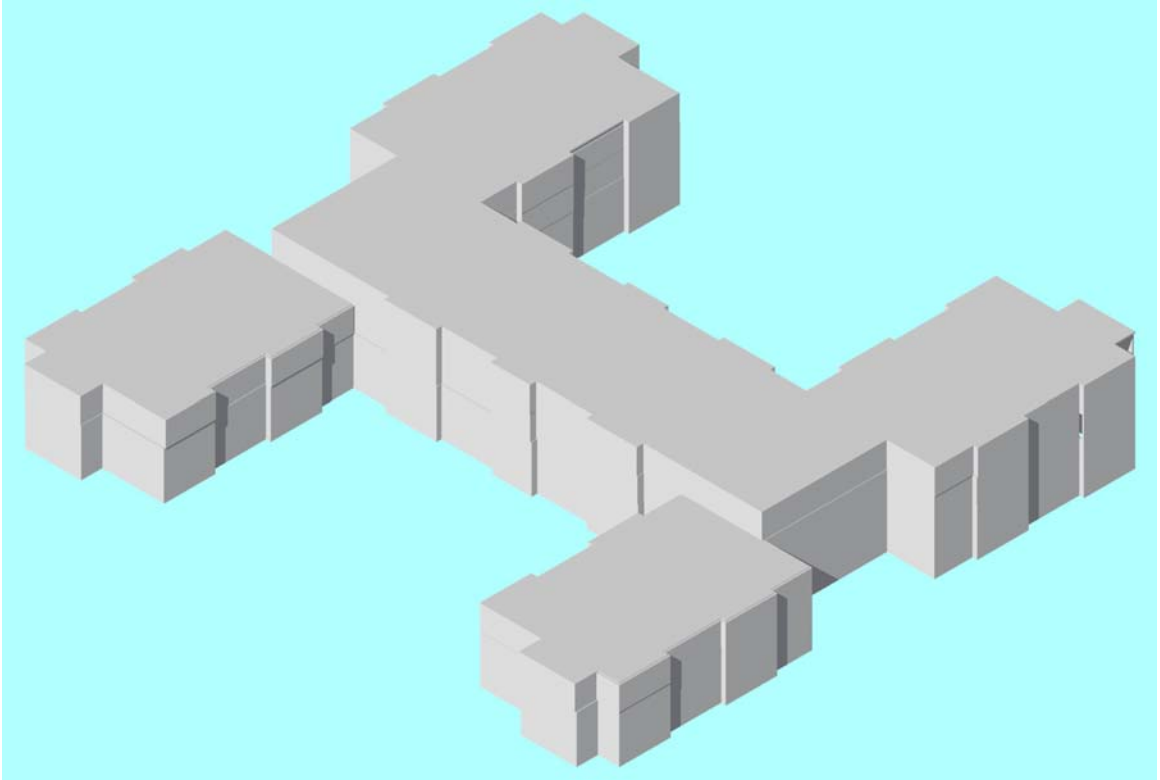
Appendix F Phase Two: Structure Estimating Worksheets & Rendered Drawings

<u>Storey:</u>			
1	"H" Shape		
	A=	31,896	
	Cost per SF	141.15	
	Subtotal:	\$4,502,117.58	
2	"H" Shape		
	A=	31,896	
	Cost per SF	141.15	Total
	Subtotal:	\$4,502,117.58	\$16,884,383.77
3	"H" Shape		
	A=	31,896	
	Cost per SF	141.15	
	Subtotal:	\$4,502,117.58	
4	----		
	A=	21,611	
	Cost per SF	156.31	
	Subtotal:	\$3,378,031.04	

A-1, Method One

1 Four Storey building				Cost per SF
Area of one floor	21611	SF		
Total Area	86444	SF	\$	139.69
1 Three story building				
Area of one floor	5142	SF		
Total Area	15427	SF	\$	152.24
1 Three story building				
Area of one floor	5142	SF		
Total Area	15427	SF	\$	152.24
			Total Cost	\$ 16,772,728.63

A-1, Method Two



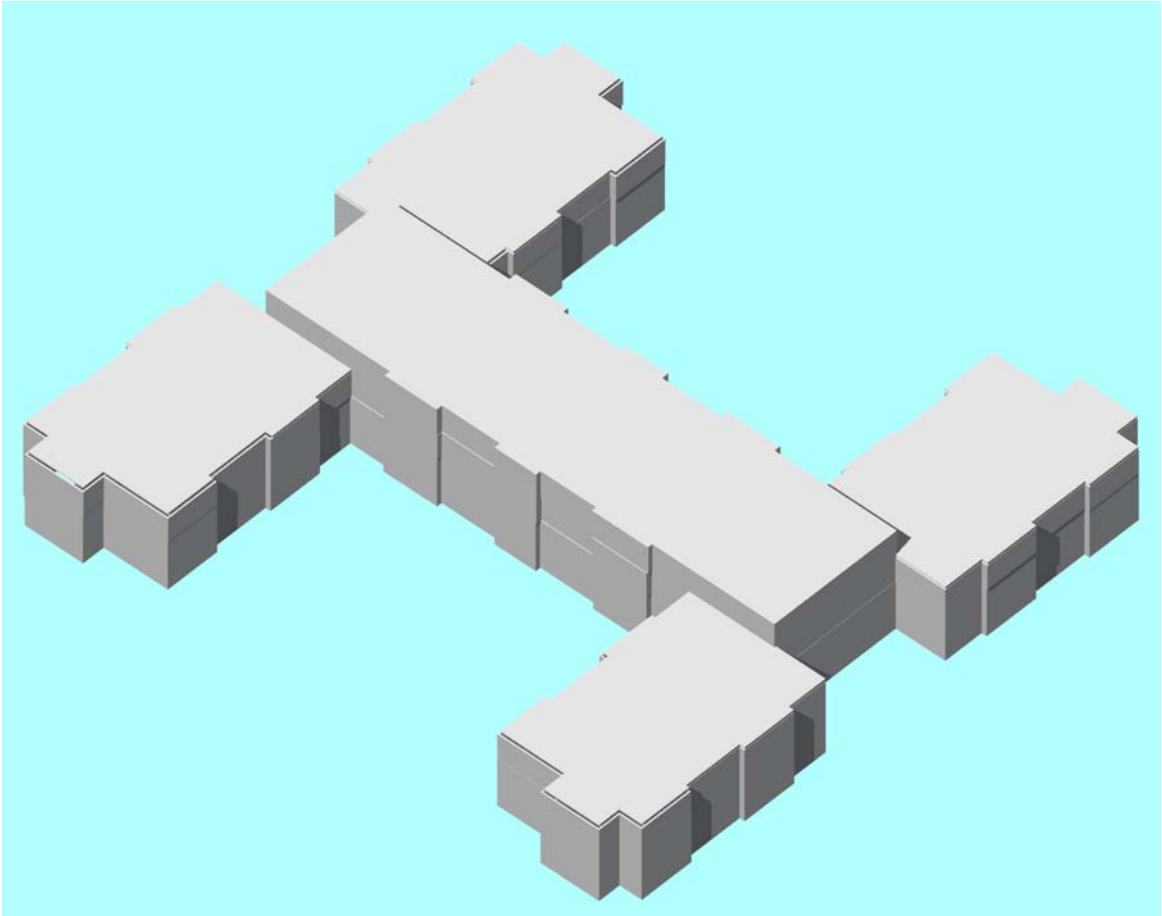
Option A-1

<u>Storey:</u>				
1	"H" Shape			
	A=	31,896		
	Cost per SF	141.15		
	Subtotal:	\$4,502,117.58		
2	"H" Shape			
	A=	31,896		
	Cost per SF	141.15		
	Subtotal:	\$4,502,117.58	Total	\$15,372,007.69
3	"H" Shape			
	A=	31,896		
	Cost per SF	141.15		
	Subtotal:	\$4,502,117.58		
4	rectangle			
	A=	11,326		
	Cost per SF	164.72		
	Subtotal:	\$1,865,654.96		

A-2, Method One

1 Four Storey building Area of one floor	11326	SF		Cost per SF
Total Area	45305	SF	\$	147.21
1 Three story building Area of one floor	5142	SF		
Total Area	15427	SF	\$	152.24
1 Three story building Area of one floor	5142	SF		
Total Area	15427	SF	\$	152.24
1 Three story building Area of one floor	5142	SF		
Total Area	15427	SF	\$	152.24
1 Three story building Area of one floor	5142	SF		
Total Area	15427	SF	\$	152.24
			Total Cost	\$ 16,063,952.17

A-2, Method Two



Option A-2

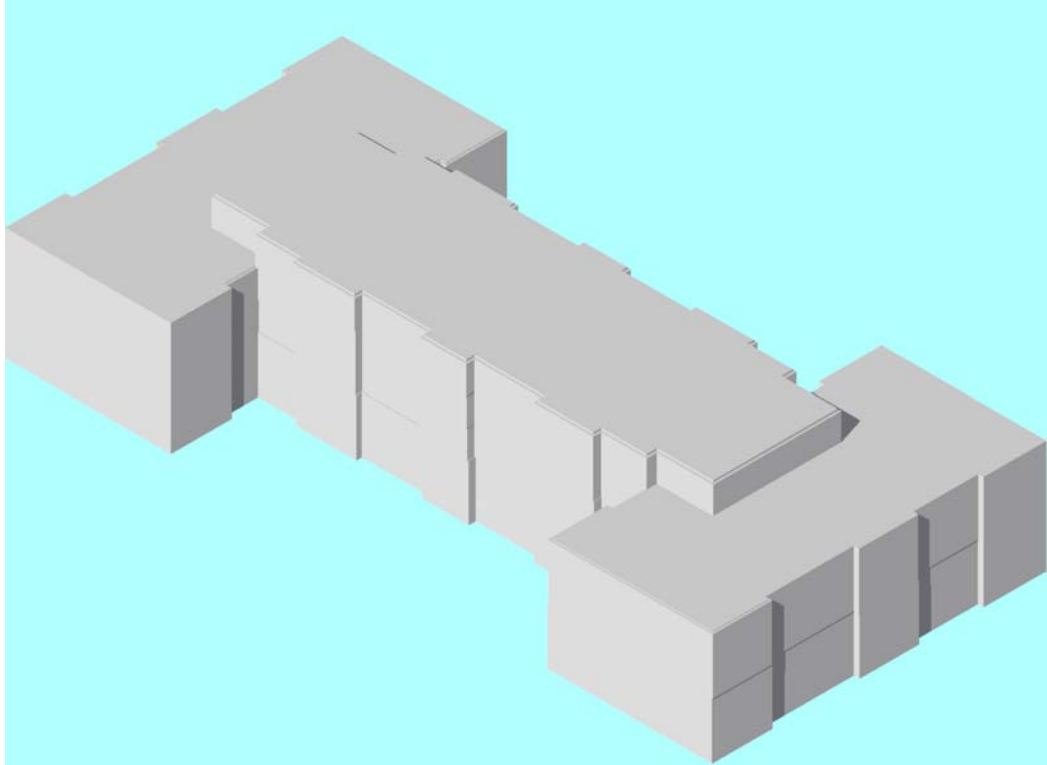
<u>Storey:</u>			
1	"I" Shape		
	A=	23,361	
	Cost per SF	145.8	
	Subtotal:		\$3,406,068.79
2	"I" Shape		
	A=	23,361	
	Cost per SF	145.8	
	Subtotal:		\$3,406,068.79
3	"I" Shape		
	A=	23,361	
	Cost per SF	145.8	
	Subtotal:		\$3,406,068.79
4	"I" Shape		
	A=	23,361.24	
	Cost per SF	155.33	
	Subtotal:		\$3,628,701.41
5	rectangle		
	A=	9,809	
	Cost per SF	166.66	
	Subtotal:		\$1,634,724.61
	Total		\$15,481,632.39

E, Method One

Option E Method Two

1 Five Storey building			Cost per SF
Area of one floor	9809	SF	
Total Area	49044	SF	\$ 146.26
1 Four story building			
Area of one floor	6776	SF	
Total Area	27105	SF	\$ 153.47
1 Four story building			
Area of one floor	6776	SF	
Total Area	27105	SF	\$ 153.47
Total Cost	\$		15,492,740.26

E, Method Two



Option E

Appendix G Phase Two: Suite Estimating Worksheets

Room	Piece		Mat.	Inst.		Total
Average suite						
	sink		\$470.00		\$480.00	\$950.00
	toilet		\$505.00		\$440.00	\$945.00
	shower		\$970.00		\$470.00	\$1,440.00
	sink (2)		\$296.00		\$410.00	\$706.00
	windows (6)		\$300.00		\$200.00	\$3,000.00
	main door	steel	\$400.00		\$400.00	\$800.00
	room doors (8)	wood	\$200.00		\$300.00	\$4,000.00
	closet doors (6)		\$150.00		\$200.00	\$2,100.00
	carpeting	1617 sq. ft.				\$6,904.59
	tile	440 sq. ft.				\$8,240.63
					Total for average suite	\$32,576.56
	location factor		1.12			
	Worcester MA					

Suite Cost Analysis

Appendix H Phase Two: Parking Garage Estimating Worksheets

Cost Estimate for Garage In Option A
proposed garage to be 61,071 sq. ft.

Area (sq.ft.)	50000	61071	75000
Cost/sq.ft. (\$)	\$41.80	\$41.00	\$40.00
total cost of garage	\$2,090,000.00	\$2,503,911.00	\$3,000,000.00

total cost of underground garage with Inflation = \$4,304,254.92
and Commercial Location Factor of 1.08 for Worcester MA

- Option A Garage Estimate

Cost Estimate for Garage In Option E
proposed garage to be 65,541 sq. ft.

Area (sq.ft.)	50000	65541	75000
Cost/sq.ft. (\$)	\$41.80	\$40.68	\$40.00
total cost of garage	\$2,090,000.00	\$2,666,207.88	\$3,000,000.00

total cost of underground garage with Inflation = \$4,583,245.32
and Commercial Location Factor of 1.08 for Worcester MA

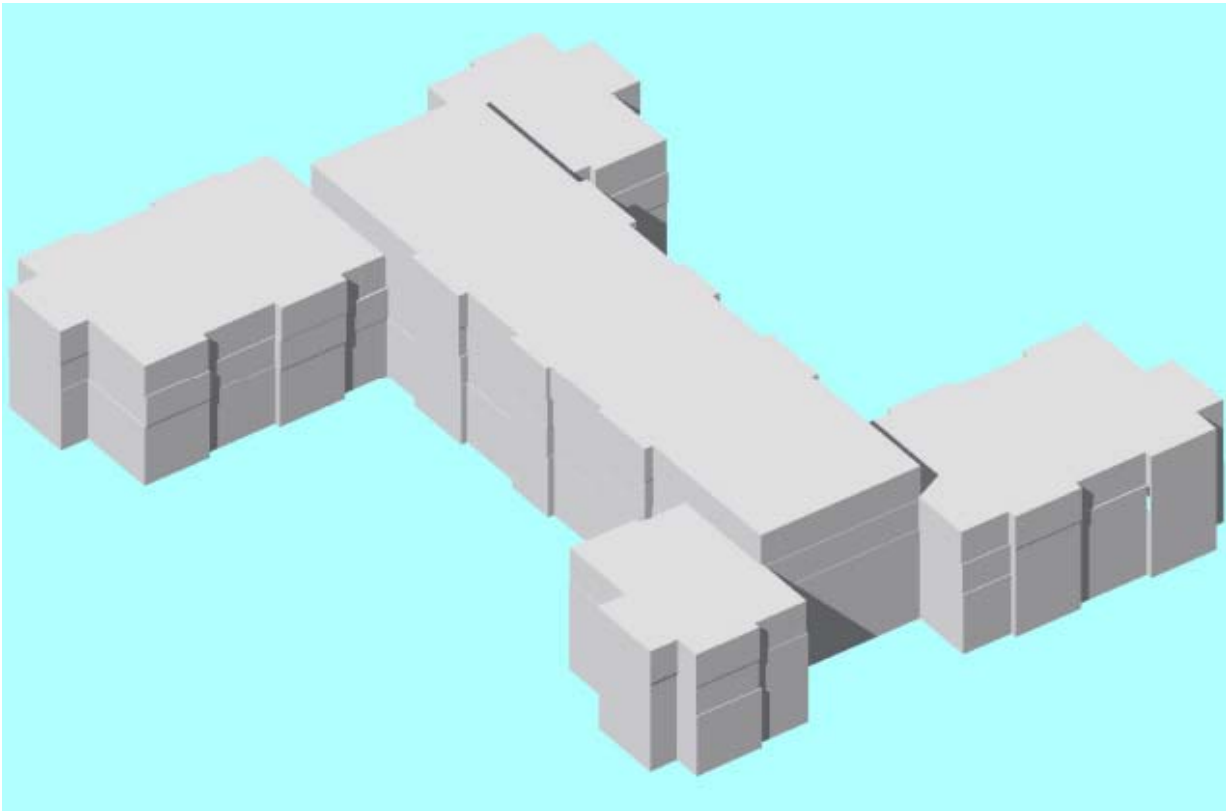
Option E Garage Estimate

Appendix I Bounding Prices Worksheets

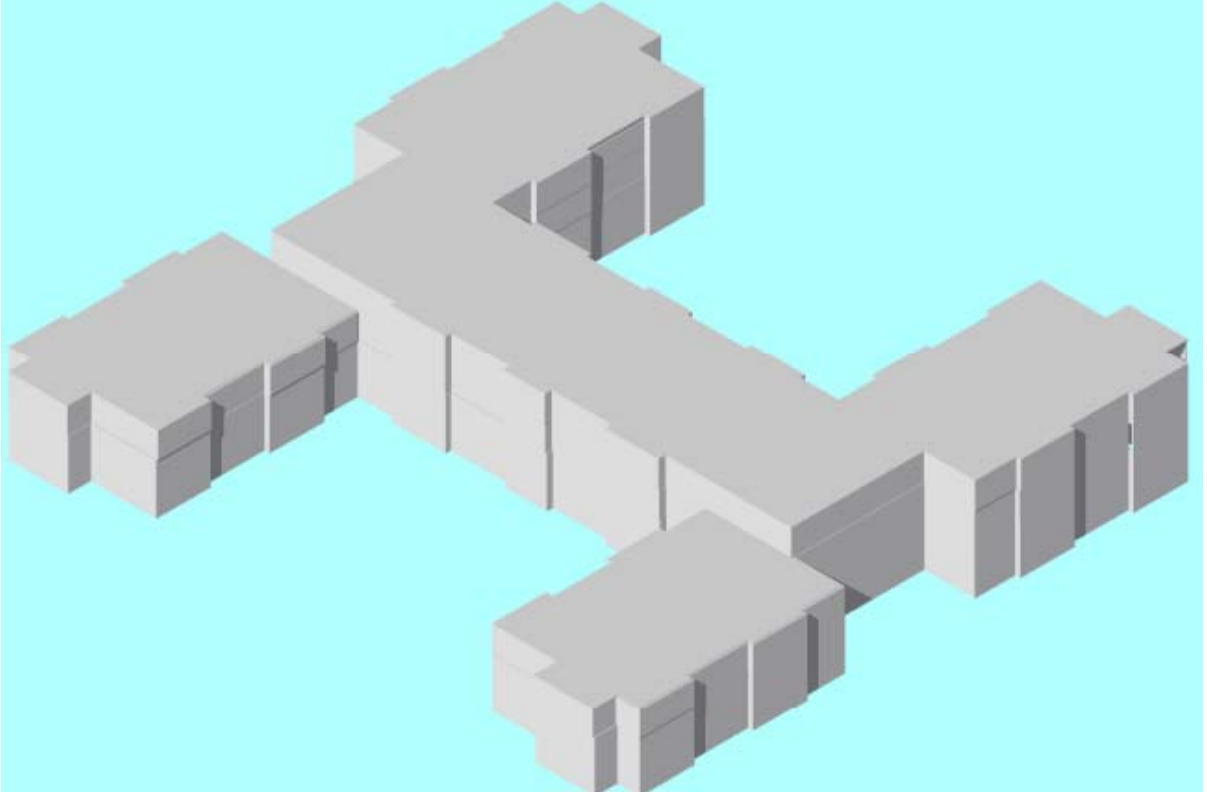
	Office Building		Motel	
	Low	High	Low	High
Foundations	\$273,181.37	\$332,135.41	\$177,138.88	\$315,528.64
Substructure	\$112,144.54	\$141,320.36	\$90,034.75	\$205,142.46
Superstructure	\$2,972,514.22	\$4,044,237.03	\$2,763,561.97	\$5,493,421.97
Exterior Closure	\$545,418.44	\$1,454,085.56	\$687,227.24	\$1,363,546.10
Roofing	\$104,199.34	\$156,299.02	\$92,476.92	\$149,786.56
Interior Construction	\$4,330,785.23	\$4,330,785.23	\$4,330,785.23	\$4,330,785.23
Conveying	\$851,341.20	\$1,261,626.12	\$656,455.87	\$1,343,683.10
Mechanical	\$3,272,510.64	\$3,272,510.64	\$3,272,510.64	\$3,272,510.64
Electrical	\$1,737,198.44	\$2,364,022.61	\$1,002,918.68	\$1,970,018.85
Special Construction	\$712,137.39	\$2,030,910.34	\$756,096.49	\$1,723,196.65
Site work				
total	\$14,911,430.82	\$19,387,932.32	\$13,829,206.67	\$20,167,620.19

Pricing by Division

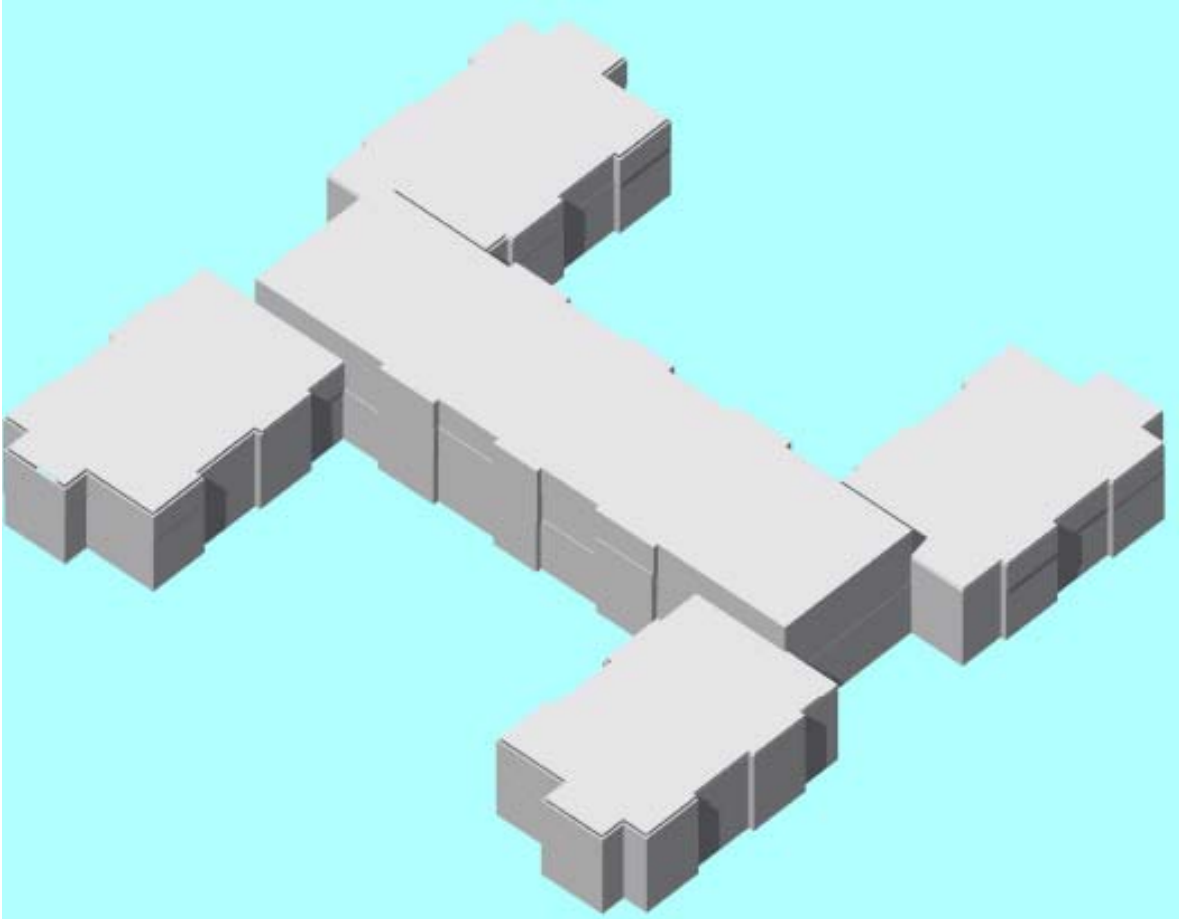
Appendix J REVIT Rendered Examples



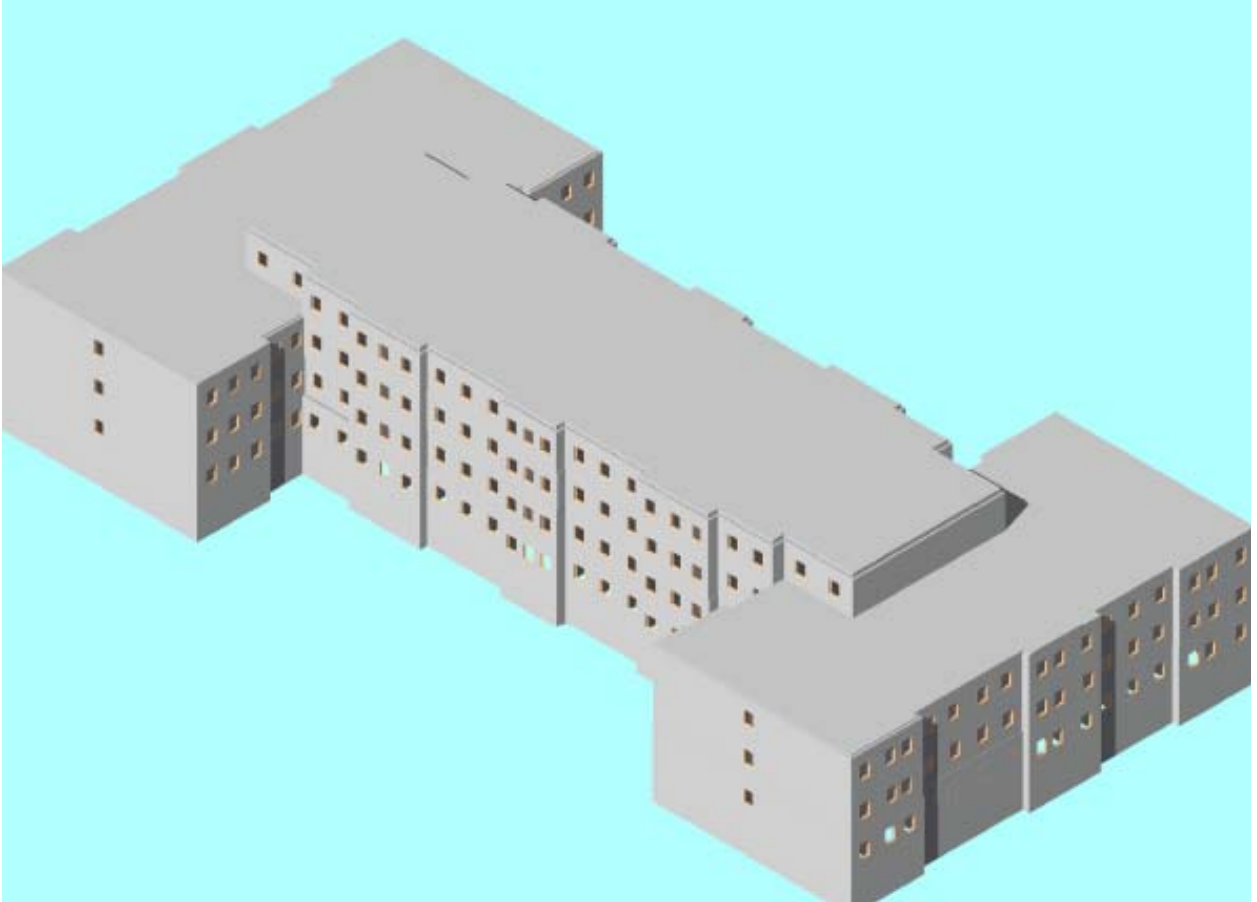
Extended 'H' shape Option B-2



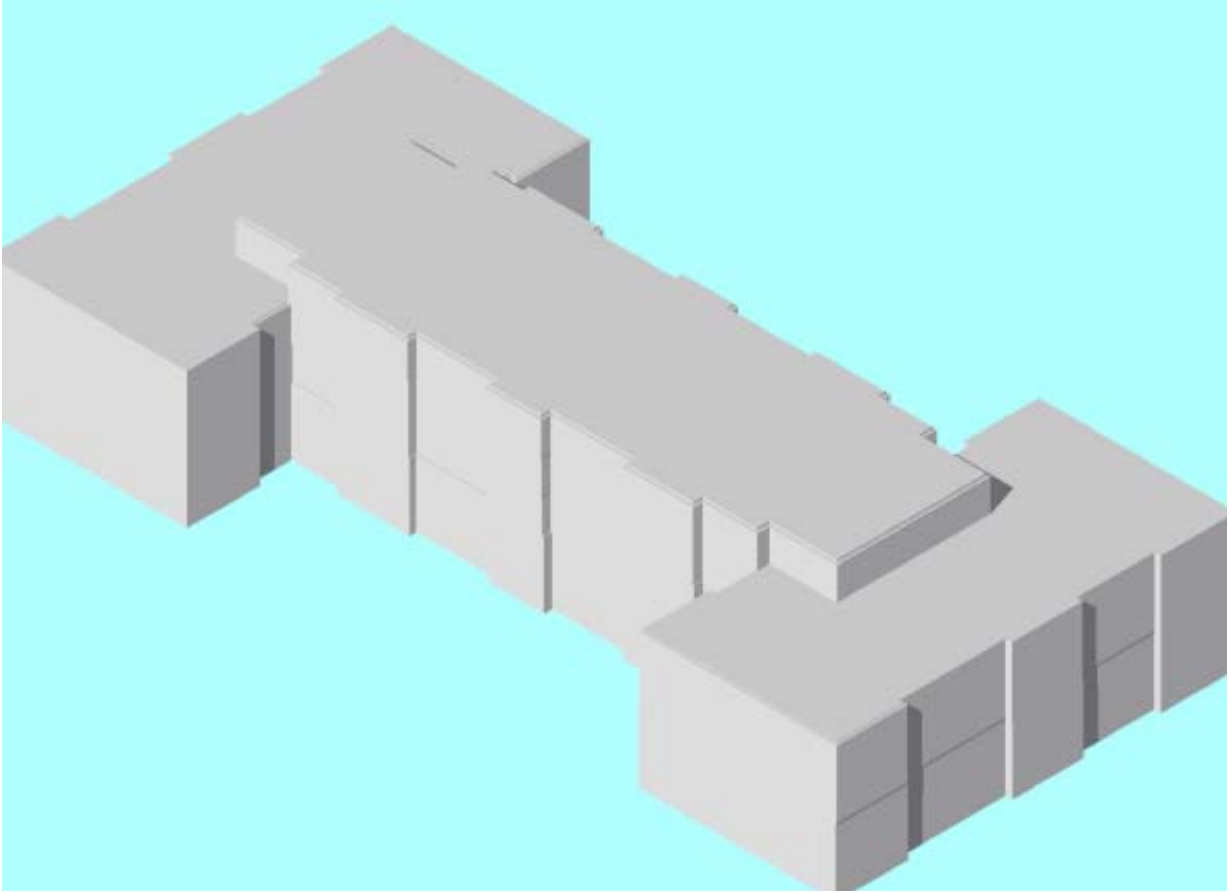
'H' shape Option A-1



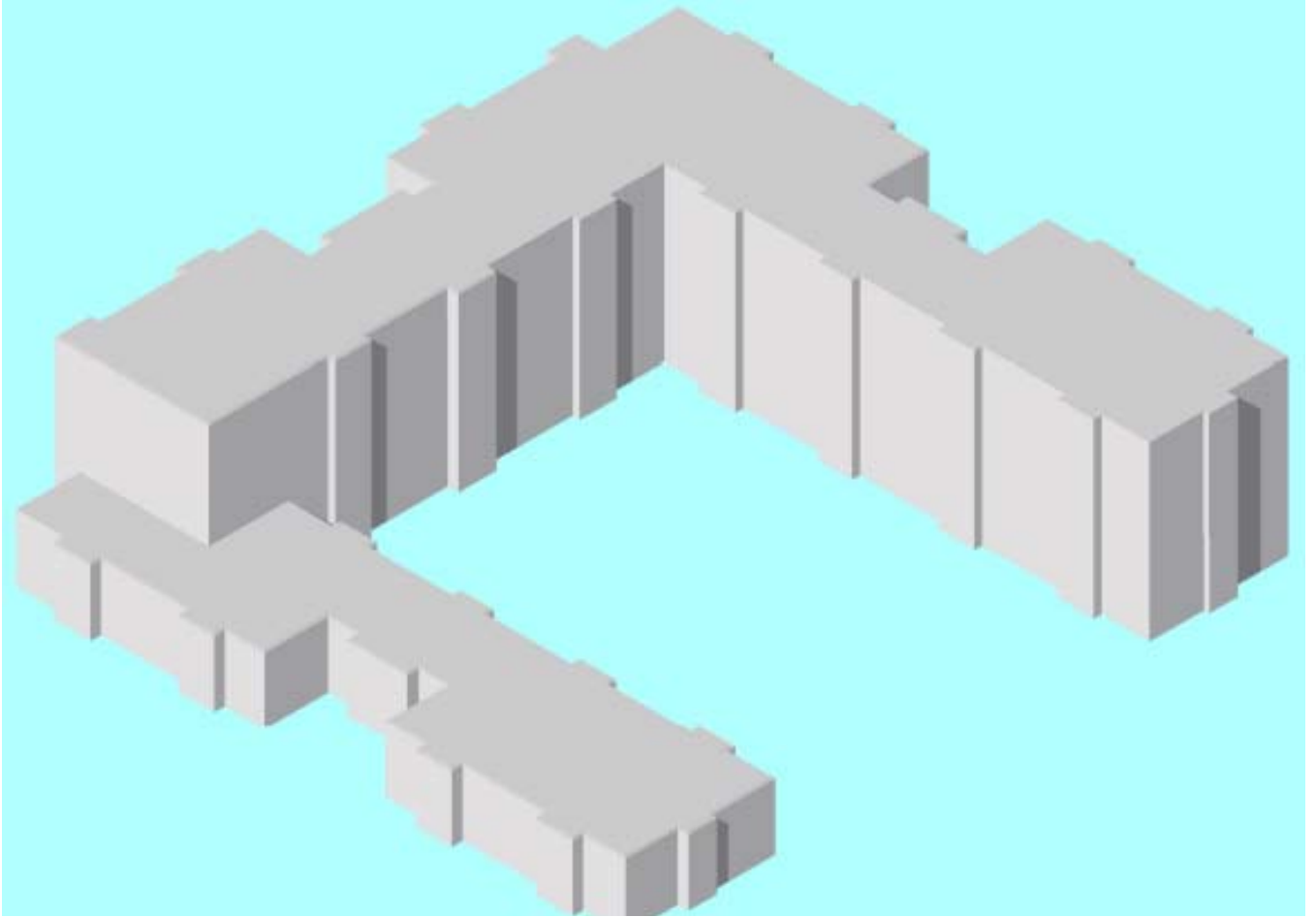
'H' shape Option A-2



'I' shape Option E incl. windows



'I' shape REVIT Option E



Scheme Two

Appendix K Example of Script File (partial)

Regular Roof

```

"Structural Framing Schedule" "" "" "" ""
"Cost" "Family" "Structural Usage" "Type" "Length"
"" "" "" "" ""
"57.25" "W-Wide Flange" "Girder" "W14X109" "30' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "30' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""
"57.25" "W-Wide Flange" "Girder" "W14X109" "20' - 0""

```


Green Roof

"Structural Framing Schedule"	"	"	"	"
"Cost"	"Family"	"Structural Usage"	"Type"	"Length"
"	"	"	"	"
"111.05"	"W-Wide Flange"	"Girder"	"W18X158"	"6' - 0"
"111.05"	"W-Wide Flange"	"Girder"	"W18X158"	"6' - 0"
"111.05"	"W-Wide Flange"	"Girder"	"W18X158"	"6' - 0"
"111.05"	"W-Wide Flange"	"Girder"	"W18X158"	"6' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"36' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
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"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
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"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"
"37.05"	"W-Wide Flange"	"Joist"	"W12X53"	"25' - 0"

Appendix L Roof Design Worksheets

Beams

Design Data:

Beams are: 5 ft on center

Beams span: 54 ft

The floor system consists of a: 5.25 in. thick concrete slab composite

The concrete compressive strength, f'_c : 3500 psi

3.5 ksi

The steel conforms to A992:

Fy: 50 ksi

Fu: 65 ksi

The interior ceiling is an acoustical ceiling supported by a suspended grid of sheet metal members.

From the Massachusetts State Building Code (MSBC):

Snow 175 lb/ft

Ceiling 25 lb/ft

M & E 50 lb/ft

Roof DL 35 lb/ft

Roof LL 100 lb/ft

Partitions allowance: 100 lb/ft

Concrete floor slab DL: 247.1875 lb/ft

Total

DL: 357.1875 lb/ft

Total

LL: 200 lb/ft

wu: 836.125 lb/ft

0.836125 k/ft

Mu: 304.7676 ft-k

use 305 ft-k

Plastic Modulus

$Z_x = \frac{(Mu \cdot 12)}{\Phi_b \cdot F_y}$

$Z_x = 86.11765 \text{ in}^3$

Beam Trials

W18 X 46

W16 X 50

W21 X 44

Adjust for Beam Weight

	Wu	Mu (ft-lb)	Req'd Z_x	Actual Z_x		Cost(\$)
W18 X 46	0.891	325	91.76471	90.7	no good	
W16 X 50	0.896	327	92.32941	92	no good	
W21 X 44	0.889	325	91.76471	95.8	good	\$31.00 use this

Girders

Design Data:

Beams are: 5 ft on center

Girders span: 40 ft

The floor system consists of a: 5.25 in. thick concrete slab composite

The concrete compressive strength, f'_c : 3500 psi

3.5 ksi

The steel conforms to A992:

F_y : 50 ksi

F_u : 65 ksi

beam

wu: 836.125 lb/ft

girder

wu: 12541.88 lb/ft 25083.75

12.54188 k/ft

Mu: 2508.375 ft-k 12541.88

use 2509 ft-k 2508.375

Plastic Modulus

$Z_x = \frac{(M_u * 12)}{\Phi_b * F_y}$

$Z_x = 708.4235 \text{ in}^3$

Beam Trials

W36 X 182

W14 X 370

W24 X 250

Adjust for Beam Weight

	W_u	M_u (ft-lb)	Req'd Z_x	Actual Z_x		Cost(\$)	
W36 X 182	12.760	2553	720.8471	718	no good		
W14 X 370	12.986	2598	733.5529	736	good	\$212.75/lf	
W24 X 250	12.842	2569	725.3647	744	good	\$144.0/lf	use this

Appendix M Green Roof Design Worksheets

Beams

Design Data:

Beams are: 5 ft on center

Beams span: 54 ft

The floor system consists of a: 5.25 in. thick concrete slab composite

The concrete compressive strength, f_c : 3500 psi

3.5 ksi

The steel conforms to A992:

Fy: 50 ksi

Fu: 65 ksi

The interior ceiling is an acoustical ceiling supported by a suspended grid of sheet metal members.

From the Massachusetts State Building Code (MSBC):

Snow 175 lb/ft

Ceiling 25 lb/ft

M & E 50 lb/ft

Roof DL 35 lb/ft

Roof LL 500 lb/ft

Soil 233.333 lb/ft

Concrete floor slab DL: 247.188 lb/ft

Total

DL: 590.521 lb/ft

Total LL: 500 lb/ft

wu: 1596.125 lb/ft

1.596125 k/ft

Mu: 581.788 ft-k

use 582 ft-k

Plastic Modulus

$Z_x = (Mu \cdot 12) / \Phi_b \cdot F_y$

$Z_x = 164.3294 \text{ in}^3$

Beam Trials

W12 X 106

W21 X 73

Adjust for Beam Weight

	Wu	Mu (ft-lb)	Req'd Z_x	Actual Z_x		Cost(\$)	
W12 X 106	1.723	629	177.6	164	no good		
W21 X 73	1.684	614	173.3647	172	no good		
W16 X 89	1.703	621	175.3412	176	good	\$35.38	use this

Girders

Design Data:

Beams are: 5 ft on center

Girders span: 40 ft

The floor system consists of a: 5.25 in. thick concrete slab composite

The concrete compressive strength, f'_c : 3500 psi

3.5 ksi

The steel conforms to A992:

F_y : 50 ksi

F_u : 65 ksi

beam

w_u : 1596.125 lb/ft

girder

W_u 23941.88 lb/ft 47883.75

23.94188 k/ft

M_u : 4788.375 ft-k 23941.88

use 4789 ft-k 4788.375

Plastic Modulus

$Z_x = (M_u * 12) / \Phi_b * F_y$

$Z_x = 1352.188 \text{ in}^3$

Beam Trials

W36 X 328

W40 X 327

W33 X 354

Adjust for Beam Weight

	W_u	M_u (ft-lb)	Req'd Z_x	Actual Z_x		Cost(\$)	
W36 X 328	24.335	4868	1374.494	1380	good	\$190/lf	use this
W40 X 327	24.334	4867	1374.212	1410	good		
W33 X 354	24.367	4874	1376.188	1420	good	\$204.25/lf	

Appendix N Roofing Material Costs

Regular Roofing

Material	Unit Price (\$)	Unit	Amount	Unit	Cost
Metal Decking	0.61	sf	18059	sf	11015.99
Protection Board	0.76	sf	18059	sf	13724.84
EPDM Single Ply	2.22	sf	18059	sf	40090.98
Insulation	1.25	sf	18059	sf	22573.75
Flashing	3.14	sf	1021	sf	3205.94
Wood Blocking	8.69	lf	896	lf	7786.24
Fire Protection	1.34	sf	18059	sf	24199.06
Concrete	176.43	cy	6615.38	cy	43227.83
Structural Steel					
Beams	21.00	lf	3934	lf	82614
Girders	57.25	lf	1504.00	lf	86104
Shear Studs	1.86	ea	361180		671794.8
				Total	1006337.4

Appendix O Green Roof Material Costs

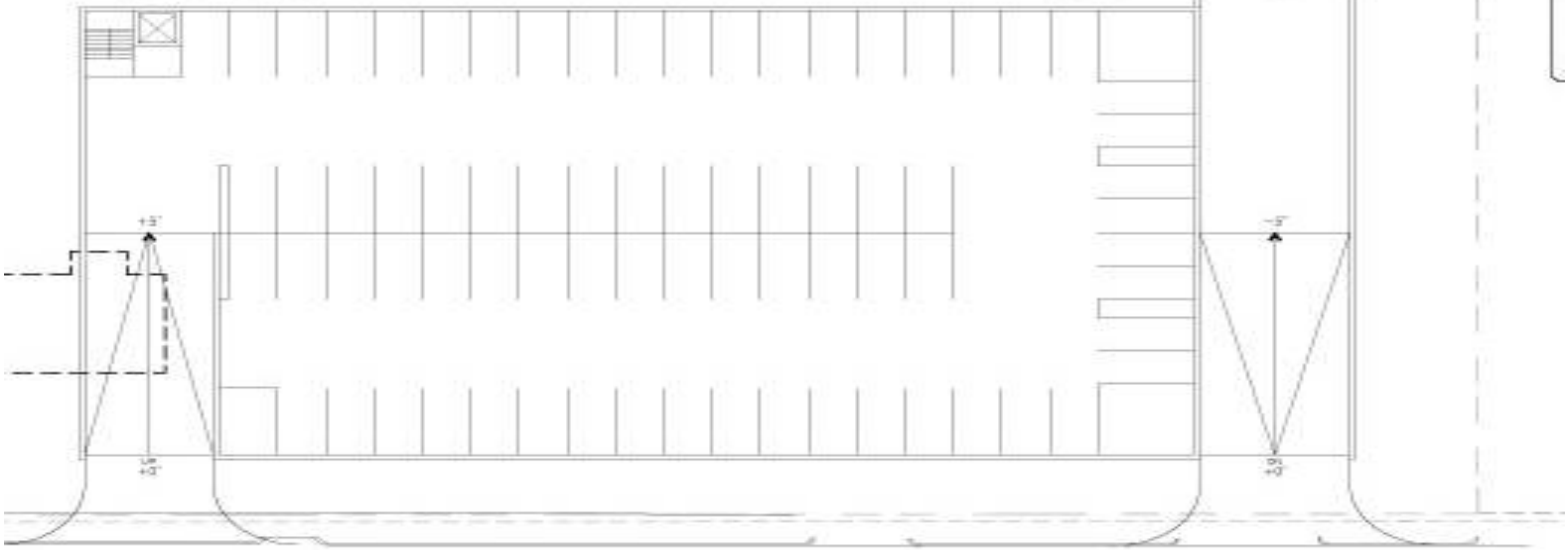
Green Roof Material Cost

Material	Unit Price (\$)	Unit	Amount	Unit	Cost
Metal Decking	0.61	sf	18059	sf	11015.99
Protection Board	0.76	sf	18059	sf	13724.84
EPDM Single Ply	2.22	sf	18059	sf	40090.98
Insulation	1.25	sf	18059	sf	22573.75
Flashing	3.14	sf	1021	sf	3205.94
Wood Blocking	8.69	lf	896	lf	7786.24
Fire Protection	1.34	sf	18059	sf	24199.06
Concrete	176.43	cy	6615.38	cy	43227.83
Structural Steel					
Beams	37.05	lf	3934	lf	145754.70
Girders	111.05	lf	1524	lf	169240.20
Shear Studs	1.86	ea	361180		671794.80
Soil	230.00	cy	245.01		56353.24
				Total	1208967.57

Appendix P Aerial Photo with Superimposed Structure and Building



BOYNTON STREET



DEAN STREET