

AMERICAN ART MUSEUM | NORTHEAST UNITED STATES

THESIS PROPOSAL

SECOND REVISION
ADVISOR: SUSTERSIC
MARCH 13, 2013

EXECUTIVE SUMMARY

This proposal presents a scenario in which the architect has requested a study that investigates an alternative structural system that does not include the use of a column at the location of 3-M.5 (shown in Figure 1). While removing a column could be, in most cases, resolved by the use of a transfer girder, column 3-M.5 is central to the structural and architectural schemes as well as the cost and constructability. The column is the last support for the level 5 cantilever at the south east corner, and is responsible for carrying over 1.8 million lbs. (1800 k) to the foundations.

Column 3-M.5 will be replaced by two new gravity trusses, one at level 5 along the East wall, and one along the exterior wall of the open office spaces at levels 3 and 4. The new structure will interrupt the current window placement at the three levels mentioned, and significant changes will need to be made to ensure that the daylight plan and architectural themes are adequately applied to AAM.

The façades at the affected areas will be considered as part of a larger architectural language being developed within AAM. Trusses will be made visible in office spaces on the interior of the buildings, and glazing will be placed in front of these trusses to make the structure visible from the building's exterior. Structural alterations that impact the public gallery spaces will be designed to do so in a minimal fashion. This new theme will allow the public to read the building from the exterior; windows in public spaces will reveal expansive, uninterrupted areas, while windows in office areas will reveal the structure first.

Furthermore, a design without column 3-M.5 will increase the cost of the building, and likely the construction duration. Changes to the architecture and structure will be carefully documented and presented in contrast to the current design.

It is important to note that this investigation intends to verify and support the decision to use a column at the location of 3-M.5 and in no way suggests the feasibility or superiority of an alternative option. The cover image, other renderings and drawings are used with the permission of RPBW.



Figure 1: Rendering of AAM showing column 3-M.5

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INTRODUCTION

The American Art Museum (AAM) will serve as a replacement to the owner's current facility in New York City. Figure 2 shows AAM's new location in a vibrant district where aging warehouses, distribution centers, and food processing plants are being renovated and replaced by art galleries, shops, and offices. AAM will stand in place of several such warehouses, and will provide a magnificent new southern boundary to the city's recently renovated elevated park, which terminates on the eastern edge of the site.



Figure 2: Aerial map showing urban location along river (www.maps.google.com)

Renzo Piano's approach to AAM's design and architecture blends a contemporary architectural style with the historical development of the city. The large cooling towers and outdoor terraces that step back towards the river on the west trace their roots back to the industrial revolution and its local impact. These outdoor terraces will also provide views of the southern skyline and space for outdoor exhibits and tall sculptures while being protected from any wind by the higher portions of the building's west side. Alternately, the large cantilevers, insets, large open spaces, exposed structural steel, and modular stainless plate cladding show no attempt to camouflage AAM with the more historical surrounding buildings.

AAM's façade is comprised of the aforementioned steel plate, pre-cast concrete, and glazing using a standard module of 3'-4" (about 1m) (shown in Figure 3). While most of the façade components are broken at each story, the long steel plates stretch 60' on the southern wall from levels 2 to 6 and from 6 to 9.

This new facility is a multi-use building with gallery and administration space, two café/restaurants, art preservation and restoration spaces, a library, and a 170-seat theater. Public space including the theater, classrooms, restaurants, and galleries are located on the south half of the building on the ground level and levels 5 through 8. Mechanical, storage, conservation, offices, and administration are dispersed on the north side at each level. The 220,000 square-foot AAM will stand 148ft tall and cost approximately \$266 million. Construction began in May 2011 and is expected to be complete in December 2014.

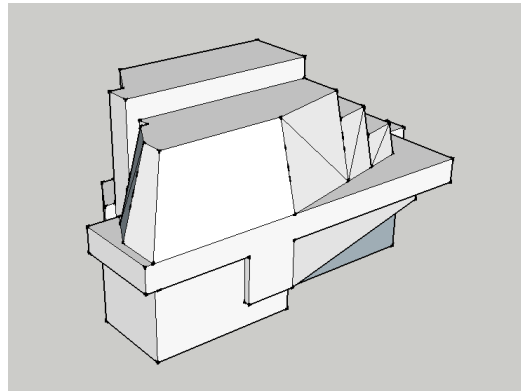
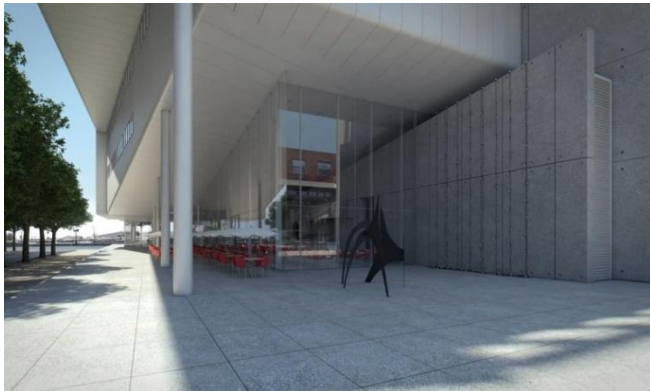


Figure 3 (left): Rendering shows façade at SE corner entrance
Figure 4 (right): Sketchup model shows building's complex geometry from the SW corner

TECHNICAL BACKGROUND AND OVERVIEW

STRUCTURAL SYSTEMS

OVERVIEW

AAM sits on drilled concrete caissons encased in steel with diameters of either 9.875" or 13.375" with pile caps. From the foundation level at 32' below grade, 10 levels rise on steel columns and trusses. Each floor will be supported by a steel-composite system. The lateral system consists primarily of braced frames spanning several stories. At some levels however, the floor system uses HSS diagonal bracing between beams and girders to create a rigid diaphragm that also transfers the lateral loads between staggered bracing. Moment frames are used for localized stability purposes. While masonry is used in AAM it is used for fire rating purposes only.

The building classifies as Occupancy Category III. This is consistent with descriptions of "buildings where more than 300 people congregate in one area" and "buildings with a capacity greater than 500 for adult education facilities."

FOUNDATIONS

URS Corporation produced the geotechnical report in February 2011 to summarize the findings of several tests and studies performed between 2008 and 2010. They summarize that while much of the site is within the boundaries of original shoreline, a portion of the western side is situated on fill-in from construction. They explain further that the portion that was formerly river has a lower bedrock elevation and higher groundwater. Due to the presence of organic soils and deep bedrock, URS suggested designing a deep foundation system and provided lateral response tests of 13.375" diameter caissons socketed into bedrock.

The engineers acted on the above suggestions and others. The caissons are specified with a 13.375" diameter of varying concrete fill and reinforcement to provide different strengths to remain consistent with URS Corp's lateral response tests. Low-capacity caissons (9.875" diameter) are individually embedded in the pressure slab, while typical and high-capacity caissons are placed in pile caps consisting of one or two caissons. The high-capacity caissons are always found in pairs and are located beneath areas of high live load or where cantilevers are supported.

A pressure slab and the perimeter secant-pile walls operate in tandem to hold back hydrostatic loads created by the soil and groundwater below grade. The walls vary between 24" and 36" and are set on 6'-6" wall footers and caissons. These are isolated from the pressure slab. The cellar level floor slab consists of a 5" architectural slab-on-grade by a 19" layer of grave on top of a 24" pressure slab (Figure 5).

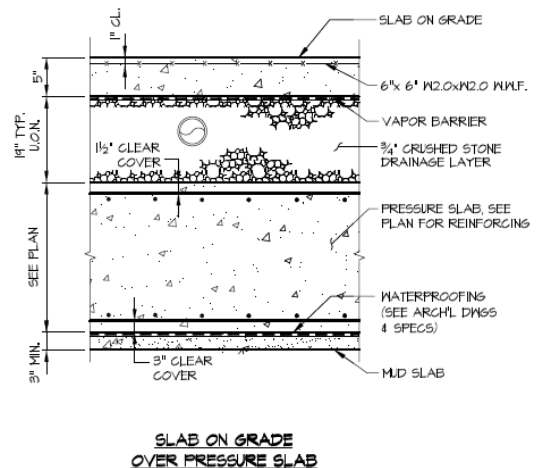


Figure 5: Pressure slab detail (S-201)

GRAVITY SYSTEM

FLOOR SYSTEM

A surprisingly regular floor layout contrasts the obscure geometry of the building (Figure 6). The engineers managed to create a grid with spacings of roughly 20' (E-W) and 30' (N-S), where the 20' sections are divided by beams which support the floor decking running E-W. Beams that do not align with the typical perpendicular grid indicate a change of building geometry below or above. Each beam is designed for composite bending with the floor slab.

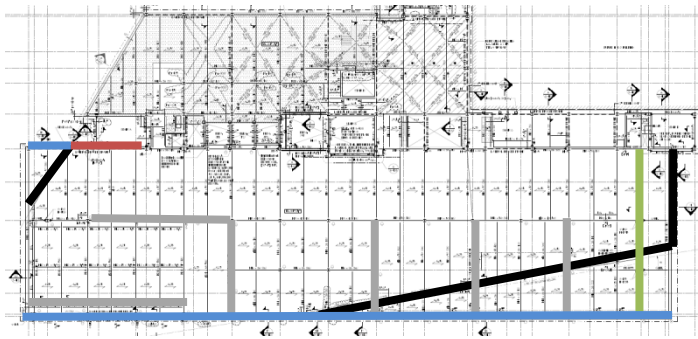


Figure 6: Level 5 framing plan showing regular layout against building footprint (S-105)

- Gravity Trusses (above)
- Gravity Trusses (below)
- Plate Girder (d=46")
- Lateral Braced Frames (part of gravity)
- Outline of Building Below

Four slab/decking thicknesses are called for depending on deck span and loading, all on 3" - 18 gauge composite metal deck. The most common callout is 6.25" (total thickness) lightweight concrete. This provides a 2-hour fire rating. 7.5" normal weight is used on level 1 for outdoor assembly spaces and the loading dock, and 9" normal weight is used for the theater floor. The roof above the level 9 mechanical space calls out 5.5" composite.

While the layout can be considered relatively consistent, the beam sizes and spans selected suggest a much more complicated floor system. Though a typical bay spans 20'-30', the gallery floors

(levels 6-8) span over 70'. The shorter spans require filler beams as small as W14x26, but the longer spans supporting the upper gallery levels require beams as large as W40x297s for web openings. In several places welded plate girders are specified at depths from 32.5" to 72." The plate girders are used as transfer large loads and moments as propped cantilevers, especially from gravity trusses and lateral braced frames shown in Figure 7.

FRAMING SYSTEM

Cantilevers on the south side of AAM are supported by 1 or 2-story trusses, typically running in the N-S direction. One large gravity truss runs along the southernmost column line between levels 5 and 6 to support the cantilever on the south-eastern corner of the building.

While the vast majority of columns are W12x or W14x shapes, some of the architecturally exposed steel vertical members are HSS shapes, pipes, or solid bars. Furthermore, the gravity load path goes up vertically and horizontally nearly as much as it flows directly down a column to the foundation. Figure 8 shows how large portions of the southern half of AAM's levels 3 and 4 are hung from trusses and beams on the level 5 framing system.

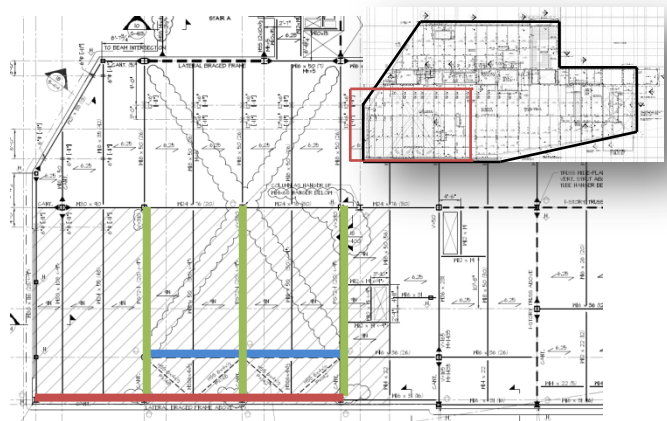


Figure 7: Level 3 framing plan showing transfer girders and lateral braced frames (S-103)

- Lateral Braced Frame (above)
- Lateral Braced Frame (below)
- Plate Girder (d=46")

Renzo Piano's designs often expose structural steel, providing an extra constraint on the design team. One example is column 3-M.5 which supports level 5 from the outdoor plaza below. The foundation column below grade specifies a W14x311, a typical shape for a column, but the architecturally exposed structural steel is called out as a solid 22" circular bar. A unique analysis would be required for a solid bar acting as a column, as AISC XIII does not have provisions for such a selection in its tables or specifications.



LATERAL SYSTEM

AAM's lateral system is as complicated as its gravity systems. A combination of moment and concentric lateral braced frames stagger up the building, transferring lateral loads via diagonal bracing within the floor diaphragms on level 3 for the southern portion and 5 for the northern portion as shown in Figure 9. Most of the braced frames terminate at ground level, but three extend all the way down to the lowest level. Those braces that terminate at upper floors transfer uplift through columns that extend underneath them. Bracing members are comprised mostly of W10x, 12x, or 14x shapes in X-braces or diagonals. There are, however, HSS shapes are used with K-braces. An enlarged floor framing plan showing the braced frames at level 5 is provided in Figure 10 below.

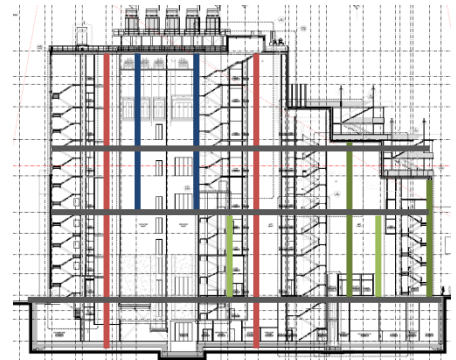


Figure 9: Section cut showing N-S braced frame discontinuities (A-212)



Figure 10: Level 5 Framing Plan Showing Lateral System (S-105)
 — Lateral Braced Frame
 — Gravity Truss that Contributes to Lateral System
 ■ Floor System with Diagonal Bracing

DESIGN CODES & STANDARDS

The design codes listed for compliance of structural design can be inferred from drawing S-200.01 and Specification Section 014100.2.B:

- International Code Council, 2007 edition with local amendments including:
 - Building Code
 - Fire Code
- ASCE 7-05: Minimum Design Loads for Buildings and other Structures
- ACI 318 -08: Building Code Requirements for Structural Concrete (LRFD)
- AISC XIII: Specifications for Structural Steel Buildings (LRFD)
- AWS D1.1: American Welding Society Code for Welding in Building Construction

Other codes not applicable to the structural systems of the building can be found in the specifications.

MATERIALS SPECIFICATIONS

The different materials specifications are summarized in Figure 11 below. Additional information can be found on drawing S-200.01 in Appendix A.

| Materials Specifications | | | | | | |
|--------------------------|---|--------------|---------------------|----------|-----|-------------|
| Concrete & Reinforcement | | | Structural Steel | | | |
| Wt | Use | f'c (psi) | Shape | ASTM | Gr. | Fy (ksi) |
| LW | Floor Slabs (typ) | 4000 | Wide Flange | A992 | - | 50 |
| NW | Foundations (walls, slab, pile caps, grade beams) | 5000 | Hollow Structural | A500 | B | 46 |
| | | | Structural Pipe | A501/A53 | -/B | 30 |
| NW | Composite Column Alternate | 8000 | Channels | A36 | - | 36 |
| NW | Other | 5000 | Angles | A36 | - | 36 |
| | | | Plates | A36 | - | 36 |
| Gr. | Use | ASTM | Connection Bolts | A325-SC | - | 80 |
| 70 | Reinforcement | A185 | (3/4") Anchor Bolts | F1554 | 36 | 36 |
| 70 | Welded Wire Fabric | A185 | | | | |

Figure 11: Summary of Structural Materials Specifications in AAM

GRAVITY LOADS

LIVE LOADS

Typically, one would expect to see Live Loads calculated from ASCE 7 minimums (ASCE 7 Table 4-1). The structural narrative explains that much of AAM does not fit with any ASCE 7 descriptions of use types, so the engineers have provided their own design loads summarized in Figure 12. Additionally the engineers created a live load plan on S-200.01 in Appendix A which shows areas of equal live load on each floor.

The engineers, in a desire for maximum flexibility of the gallery spaces, elected to conservatively design the AAM-specific spaces for live loads, while being consistent with ASCE 7 minimums for more common areas.

| LL Schedule Designation | | ASCE 7 Designation | |
|---------------------------------|-----------------|--------------------|-----------------------------|
| Use | LL | LL | Description |
| Gallery - Typical | 100 | 100 | Assembly Area |
| Gallery - Level 5 | 200 | 100 | Assembly Area |
| Testing Platform | 200 | 150 | Stage Floors |
| Offices | 50 | 50 | Offices |
| Private Assembly/ Museum Use | 60 | n/a | n/a |
| Auditorium - Movable Seating | 100 | 100 | Theater - Moveable Seats |
| Compact Storage | 300 | 250 | Heavy Storage |
| Art Handling & Storage | 150 | 125 | Light Storage |
| Largo and Loading Dock | AASHTO HS-20 | 250 | Vehicular Driveways |
| Stairs and Corridors | 100 | 100 | Stairs and Exit Ways |
| Lobby and Dining | 100 | 100 | Lobby Assembly |
| Mech Spaces Levels 2, 9 | 150 | n/a | n/a |
| Mech Spaces Cellar | 200 | n/a | n/a |
| Roof - Typical | 22 + S | 20 | Roof - Flat |

Figure 12: Comparison of design live loads and ASCE 7 minimum live loads

DEAD LOADS

Because the live loads (above) are so high, the design engineers were very precise in their dead load calculations. Similar to the live loads, the diversity of different use types and load requirements have led to a congruent variety of dead load arrangements in structural steel weight, concrete density, MEP requirements, partitions, pavers, roofing, and other finishes. A total of 37 different dead load requirements, arranged by use and location, are listed in the Dead Load Schedule on drawing S-200.01. These range from 76 PSF to 214 PSF. In all, AAM has a dead weight of 23,084 k (11,500 tons) from level 1 through the North Roof level. Complete dead load calculations can be found in Technical Report 1.

SNOW LOADS

ASCE 7-05 was used to calculate the snow loads for AAM in consistency with the wind and seismic loads. This code was used because it is the most recent publication of ASCE 7 per the specifications (see Design Codes & Standards above). Figure 13 details the summary of this procedure, comparing the Snow Load Parameters on drawing S-200.01 to the City Building Code/ASCE 7.

ASCE 7-05 equation 7-1 (section 7.3) states that where the ground snow load exceeds 20 PSF, the flat roof load value must not be less than $(20)I_s$. 22 PSF, the design flat roof load, is not in accordance with ASCE 7's minimum according to equation 7-1 of 23 PSF. It is important to note that the step-back terraces where drifting is a concern are designed for 100-200 PSF of live load, and it is unlikely that the building will experience snow loads exceeding those live loads. Further information on the snow load calculations can be found in Technical Report 1.

| Snow Load Comparison | | |
|----------------------|------------|------|
| Design Parameters | ASCE 7 -05 | |
| Pg | 25 | 25 |
| Ct | 1 | 1 |
| Is | 1.15 | 1.15 |
| Ce | 1 | 1 |
| Pf | 20.1 | 20.1 |
| 20 Is | 22 | 23 |

Figure 13: Snow Loads

PROBLEM STATEMENT

All previous technical reports verify that AAM is adequately and economically designed. Significant changes to the structural systems would cause unreasonable increases to the weight, cost, stability, and floor-to-floor height on levels 3, 4, and 5. Likewise, the analysis performed in Technical Report 2 disqualifies the consideration of alternative framing and floor systems.

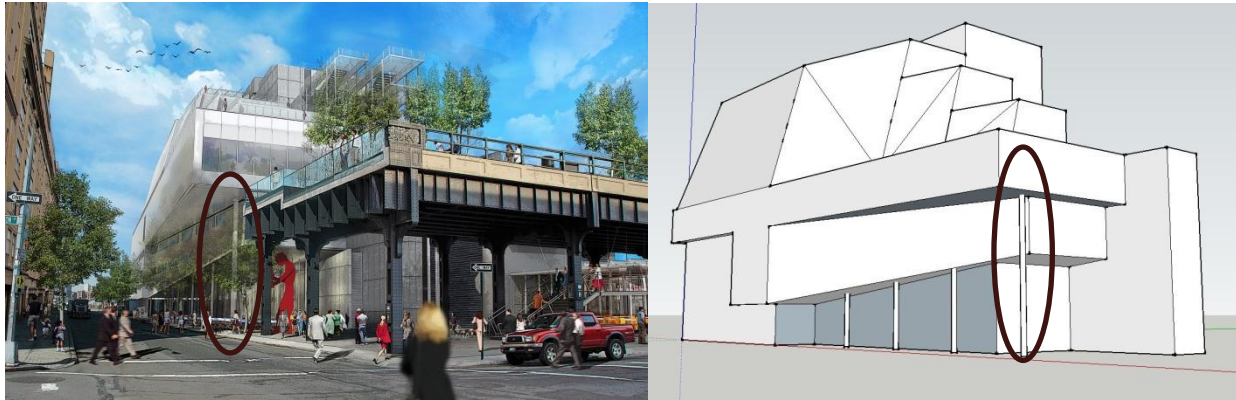


Figure 18: Rendering and Sketchup model showing column 3-M.5 from SE corner

Figure 18 above shows the geometry of AAM at the SE corner entrance and plaza space. Four architecturally exposed columns in the space run parallel to the street and coincide with the horizontal grid of AAM. Three of these columns support mass of levels 3 and 4 above the glass-enclosed lobby. The fourth column (3-M.5, circled), however, appears to be the sole support of level 5.

A scenario has arisen in which the architect has expressed interest in removing column 3-M.5. Architecturally, this 22" circular column carries the most delicately-balanced and most massive part of the building visible from street level. Though current design represents an effective and elegant solution to the stability of the cantilever, the architect has asked the structural engineer to consider a method which does not include a column at the location of 3-M.5.

PROPOSED SOLUTION

It is for the above reasons that this thesis project will explore the possibility of supporting the level 5 cantilever without the use of a column at the location of 3-M.5. Extensive changes must be made to the building's gravity load path which will affect the cost, construction schedule, and architectural themes of AAM. Additionally, this change could affect the global stability of the building.

A new load path must be introduced to redistribute the 1,800 kips carried by column 3-M.5. This new load path will require changes to the framing of the levels below and at the cantilever level. First, a two-story truss will have to be added along the south wall (non-orthogonal) on levels 3 and 4 to act as the last support at the cantilever in both directions. Secondly, a truss must be added between levels 5 and 6 at the eastern gallery wall (currently glass). Loads will then travel through the existing frame, which will be re-analyzed to accommodate the extra loads resisted by each member.

This alternative design will be compared to the current design by analyzing the cost, weight, schedule, and architectural impacts. Finally, the data will be reviewed by the architect and owner for consideration.

BREADTH TOPICS

ARCHITECTURAL BREADTH

The proposed changes to the structure of AAM will provide many challenges in respecting the current architectural scheme. Figure 18 above shows the modular façade and panel systems which conform to a 3'-4" (1 meter) grid. Furthermore, AAM's purpose as an art museum makes exposing the building's structure less desirable than in other Renzo Piano buildings, especially in the gallery spaces. The proposed structural trusses, however, will interfere with the current exterior walls' window placement in both the level 5 gallery and the office spaces below. Various models will show how these changes affect the overall language of AAM.

CONSTRUCTION BREADTH

A comparative cost analysis for the proposed structural system will be performed comparing this alternative design to the existing design. Materials and labor figures will be requested from the general contractor in order to maintain a project-specific budget and schedule. Any information that cannot be provided by the GC will be supplemented by RS Means. Also, the large trusses, some spanning two stories, will be difficult to transport to the site and assemble. Each step in the proposed truss system will be analyzed for constructability and transportation considerations.

TASKS & TOOLS

REDESIGN AAM WITHOUT COLUMN 3-M.5 (DEPTH)

1. Redesign Superstructure
 - A. Establish Load Path
 - B. Establish gravity loads from Level 6
 - C. Redesign Truss 0.9
 - D. Design Truss at N.2
 - A) Investigate Diagonal Truss
 - B) Investigate Vierendeel Truss
 - E. Design Truss at X
 - F. Use SAP2000 to assist redesign of secondary trusses
2. Construct model of AAM in ETABS
 - A. Confirm Gravity Design
 - B. Check Torsional Implications and Global Stability
3. Adjust lateral system stiffnesses (if applicable)
4. Investigate Foundations Impact
 - A. Confirm Adequacy of Caissons
 - B. Redesign as Necessary

ARCHITECTURAL IMPACTS (BREADTH 1)

1. Assign façade changes to Levels 3 and 4
2. Investigate truss 7.9 to office spaces
 - A. Confirm COR/COM does not change in ETABS
 - B. Confirm no additional torsional effects
3. Decide Vierendeel/Diagonal at Level 5
4. Revit models of relevant spaces
5. Altered spaces SQFT takeoff

CONSTRUCTION IMPACTS (BREADTH 2)

1. Track cost changes as project progresses
2. Determine cost impacts due to
 - A. Structural Steel
 - B. Architecture Alterations
 - C. Schedule Implications
3. Use schedule provided by Turner to determine any critical path changes for suspended floors or Level 5 cantilever
4. Create comparative analysis

THESIS SCHEDULE

| Proposed Thesis Semester Schedule January 2013 - April 2013 | | | | | | | | | | Sean Felton Advisor: Heather Sustersic | | | | | | | | | |
|--|-----------|--------------------------|-----------|-------------------------|-----------|--------------------------|-----------|-----------------------------|-----------|---|-----------|------------------------------|----------|---------------------------------------|-----------|--------------------|--|------------------------|--|
| Milestone 1 1/28/2013 | | Milestone 2 2/11/2013 | | Milestone 3 3/1/2013 | | Milestone 4 3/26/2013 | | Turner Project - Art Museum | | | | | | | | | | | |
| 1/7/2013 | 1/14/2013 | 1/21/2013 | 1/28/2013 | 2/4/2013 | 2/11/2013 | 2/18/2013 | 2/25/2013 | 3/4/2013 | 3/11/2013 | 3/18/2013 | 3/25/2013 | 4/1/2013 | 4/8/2013 | 4/15/2013 | 4/22/2013 | | | | |
| Redesign Superstructure | | | | | | | | | | | | Final Report Due April 3 | | Faculty Jury Presentations April 8-12 | | Senior Banquet TBA | | | |
| ETABS Model | | | | | | | | | | | | Finalize Report/Presentation | | Submit Report | | Jury Presentations | | Update CPEP and Report | |
| Level 5 Vierendeel/Diagonal | | | | | | | | | | | | Spring Break | | | | | | | |
| Truss X | | | | | | | | | | | | | | | | | | | |
| Remaining Load Path | | | | | | | | | | | | | | | | | | | |
| Foundations | | | | | | | | | | | | | | | | | | | |
| Move 7.9 | | | | | | | | | | | | | | | | | | | |
| Facade Changes | | | | | | | | | | | | | | | | | | | |
| Architectural Impact of Vierendeel/Diagonal | | | | | | | | | | | | | | | | | | | |
| Architectural Models in Revit | | | | | | | | | | | | | | | | | | | |
| SQ. ft. takeoff | | | | | | | | | | | | | | | | | | | |
| Track Structural Cost/Schedule Changes | | | | | | | | | | | | | | | | | | | |
| Track Architectural Cost/Schedule Changes | | | | | | | | | | | | | | | | | | | |
| Gather \$ info from CM | | | | | | | | | | | | | | | | | | | |
| Milestones | | | | | | | | | | | | | | | | | | | |
| 1 Primary and N.2 Secondary Truss Options Completed | | | | | | | | | | | | | | | | | | | |
| 2 X Secondary Truss completed; Major trusses in ETABS | | | | | | | | | | | | | | | | | | | |
| 3 All Depth Investigations Complete; ETABS model verified | | | | | | | | | | | | | | | | | | | |
| 4 Comparative Analysis Complete | | | | | | | | | | | | | | | | | | | |
| Depth Study: Redesign Structural System without Column 3-M.5 | | | | | | | | | | | | | | | | | | | |
| Breadth Study 1 : Architectural Impacts and Cohesive Language | | | | | | | | | | | | | | | | | | | |
| Breadth Study 2: Construction Cost and Schedule Impacts | | | | | | | | | | | | | | | | | | | |
| Submission | | | | | | | | | | | | | | | | | | | |

CONCLUSION

This proposal presents an alternative structural design which does not include the use of a column at the location of 3-M.5. In order to accommodate this provision, large gravity trusses will be added to redistribute the weight carried by the missing column. The trusses cannot simply be hidden behind walls, so the architecture will require adequate attention. Changes will be made to the façade on two levels, and to the language between public and office spaces. Finally, a comparative cost and schedule analysis will be performed to analyze the impact on the construction of the building. This data will be presented in contrast to the current design and construction schedules to evaluate the options and verify the use of Column 3-M.5 as the best possible method for AAM's design.