Synthesis between Architectural and Structural Design: Exploring the concept of large open interior spaces and a highly redundant facade.

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Abstract *— There is an architectural thesis that states that in order for a building to be permanent, it has to be impermanent. A mayor part of the thesis centered on making buildings cost-effective to reuse thus avoiding obsolescence and becoming abandoned buildings that burden the city. The question this project proposes to answer is; how to design a structure that can predict future uses by providing an open plan with minimum inner structure. The project uses the façade as a modular loading system to provide active building redundancy. The ideal of being able to be replaced for custom purposes and to have a free open space free of internal structure makes the design highly cost-effective considering the buildings life cycle. The engineering thesis will explore the idea of structural redundancy in the implementation of the modular system and how it reacts towards the maximum loads.*

Key Terms *— Cost-Effective Reuse, Perpetual Adaptation, Structural Façade, Structural Redundancy.*

EXISTING PROJECT DESCRIPTION AND CONDITIONS

Abandoned sites influence negatively on the development of the city by consuming prime real estate locations with obsolete buildings. The architectural thesis chose one of these sites to adaptively reuse it. The project consists of two primary buildings and two substructures. The primary buildings are the historical building and the new building. The substructures will consist of a parking building and a multiple studio building. For the thesis the new building will be designed with an open internal space and a redundant facade.

The site:

- **Location:** Santurce, PR (Figure 1)
- **Area**: 15,865.9837 sq. mt. (4.0371 cuerdas)
- **Occupation Area**:
  - Building 1800's: 32,069.5243 sq. ft.
  - Building 1900's: 6,088.0262 sq. ft.
  - Adjacent Building: 2699.9208 sq. ft.
  - Storage Buildings: 10,766.1370 sq. ft.
- **Floors**:
  - Building 1800's: 2 above, 1 underground
  - Building 1900's: 3 above, 1 underground
  - Adjacent Building:2 above, 1 underground
  - Storage Buildings: 1 above
- **Floor Area**:
  - Building 1800's: 69,809.4973 sq. ft.
  - Building 1900's: 19,721.8049 sq. ft.
  - Adjacent Building: 8,099.7324 sq. ft.
  - Storage Buildings: 10,766.1370 sq. ft.
- **Total Built Area**: 109,184.4496 sq. ft.
- **The soil:** Maricao - Los Guineos
  - Deep to hard rock, well-drained and clayey mixed, yellowish brown and red clay
  - Slope gradients 20º to 60º, Erosion Hazard
  - Flooding: None, High-water table: >6ft.
  - Bedrock: >60ft

Figure 1
Site and Building Chosen

ARCHITECTURAL THESIS

"Creation of space is often conceived as an action done in the present created to last. The constant renewal of the present space introduces the need to foresee the obsolescence of what is permanent. The permanent is nothing more than a perpetual disease of a random object that was thought for nothing more than a momentary status."[1]

The project is based on an architectural thesis that wanted to create permanent buildings with impermanent components. Thus overcoming building obsolescence and not burdening the city with abandoned sites.

Buildings should be impermanent and accommodate changes in societal needs through time. The thesis presented the problem of abandoned sites in the city that posed a threat to health. Often these sites are not developed because the cost-benefit is low, and potential investors won't consider them.

The thesis planned to resolve the obsolescence problem by creating a flexible and adaptable building that could survive through perpetual usage. It was proposed to prove the permanence of an abandoned historical building while at the same time designing a new impermanent building. This eliminated abandoned sites in the city in a cost-effective way.

The Program

The program to demonstrate the adaptive capabilities of structures went into the educational category, more specifically a Cinematographic University. Cinematography offers the diversity of adapting environments into different scenes and thus the building has to mutate and transform to offer the independence movies need.

The Building

The building chosen was the "Departamento de Salud" (Figure 2) complex in Santurce. Originally used as a refuge for orphan boys in the late 1800's, it has had many uses throughout the years and continues to be abandoned. Now it belongs to the "Administración de Terrenos" (as of 2008) that is planning to remodel it for renting.

The site contains the main historic building that consists of the Spanish colonial building and its addition somewhere in the mid 1900's. On the western border of the site there are small buildings, one is considered historical, however it is greatly deteriorated, and the rest are modern and are used for maintenance and storage.

Figure 2
Departamento de Salud

The Location

The location is in Santurce where there is a revitalizing movement to transform it into a theater zone. The site has a main entrance through the Ponce de León Avenue and a back exit through the community streets and other government agency buildings that discharge to the Fernández Juncos Avenue.

The site is contiguous to "Parroquia Sagrado Corazón" on the east and to the north-east the Central Highschool of San Juan. To the west has some abandoned buildings and to the north-west the new Metro Towers apartments. Directly to the north it has the remodeled "Teatro Paramount" and the street running northward ends at "Plaza del Mercado". (Figure 3)

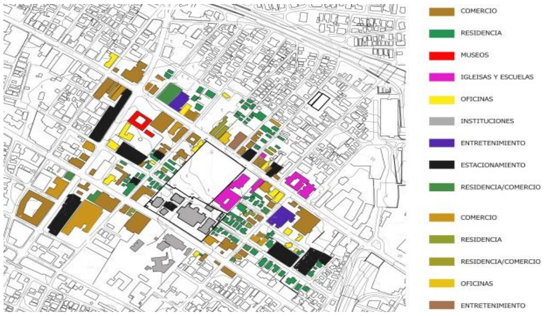


Figure 3
Surroundings

The Renovation Proposal

The architectural response was to adaptive re-use the original historical building, while a new building spans over it. The new building consisted of two flanking tower buildings connected with a truss over the historical building. (Figure 4)

The project's 9 floors had varying heights restricted to the original heights of the historical floors; the upper levels were restricted by the truss system height. The façade was composed of glass louvers which had its own support system. The floors were internally supported with columns to offer an open plan, with shear walls on opposite ends of the building which were the facades.

The proposed truss would be a single truss of 16 feet in height spanning 210 feet. It was originally supported by simple columns which were part of the flanking tower buildings. The truss would house the library and reading areas. The inner closing would be sliding glass panels and the outside closing would be the glass louver system.

The materials proposed where reinforced concrete floors with steel beams and steel columns enclosed with concrete. All steel sections would be bolt connected. The glass louver system would be supported by lightweight steel columns. The truss was composed of W sections welded together.

Figure 4
Model

STRUCTURAL CONCEPT

The projects engineering basis stems from the idea of how to design a structure that can predict future uses within it by providing an open plan. It implies that the design loads need to be adopted as those corresponding to the most demanding conceivable use. The design must be able to be strategically customizable and to reassemble the building with a different plan configuration in the future, making the design highly cost-effective considering the use cycle of the building.

The thesis will explore the idea of structural redundancy in the implementation of the modular system and how it reacts towards the maximum loads. Stating that structural redundancy arises primarily from the system's capacity to provide an alternative load-carrying path when the first primary-load resisting system fails [2], concluding that having an alternate system to carry the loads with or without a system failure can be achieved.

However, the idea is not to create a dual-system of load bearing, as this would make the structure complex and will defeat the purpose of a modular system that can be reused or replaced easily. The project will deal with creating a single system that holds redundancy, on the façade, in order to generate an open space with minimum inner structure that allows changing the spaces. The redundancy will not rely on the possibility of a system failure to kick in; it will be built with it.

The definition of redundancy through the years has been defined as the degree of indeterminacy which is the parameter used to evaluate the degree of redundancy of structures. [2] The idea was to find the weakest member of the structure and base a ratio of the collapsing loads between the building and said element, providing over-strength. In this project, the collapsing load of the weakest element defines the system, thus guaranteeing that when the system needs to rearrange its loading paths, it will find a suitable conduit somewhere else. Being a statically indeterminate structural system, the more static equilibrium equations needed to solve for reaction variables the less unique those variables become. In the end, many of these variables can cease to exist and never be noted by the system.

The project plays on the elimination of such variables at a definite state, on different locations and on different times, using as much active redundancy as possible. There are two kinds of redundancies; active and passive. Active redundancy systems have the redundant elements working alongside the main system and when the main system fails the redundant elements start working. [3] Active systems are composed of dual loading systems working in the same structure, making the system over complex but essentially complete. Meaning that both systems are equally powerful on their own, but only one system is actually providing output. [4]

Passive redundancy systems are the systems that start working when the main system fails. [3] A dual structural system that doesn't work together sharing the load, they both work independently but at different times. Both systems are equally capable of withstanding the loading, still making up a complex but complete system.

For the project the goal was to provide the redundancy using just one highly redundant loading system, in this case the façade, thereby simplifying the structure, providing an open plan and making it easy to remodel in the future. The redundancy relies on the design of the modular system itself and the structural façade will be a fundamental element of the architectural façade design.

The projects problem is; how to design a modular single loading system that can provide enough active building redundancy to support an open plan with minimal internal structure where one or more of its modules could change?

STRUCTURAL PROPOSAL EVOLUTION

There were several stages of designing the truss system and its correspondent support. The original architectural proposal of a conventional built up truss proved effective, but would require large custom made W shapes making the project unfeasible cost-wise even though it provided the open plan. (Figure 5)

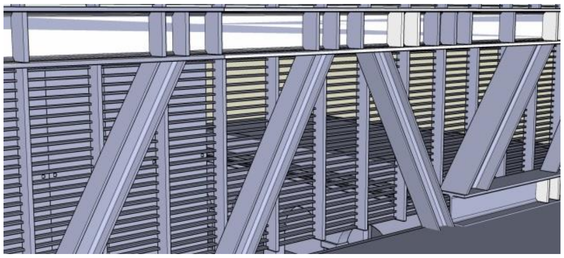


Figure 5
First Iteration

The next iteration was a three independent system; one supporting both floors and the roof (Principal), the other supporting the Principal system (Main) and the third would support both of them (Legs). (Figure 6)

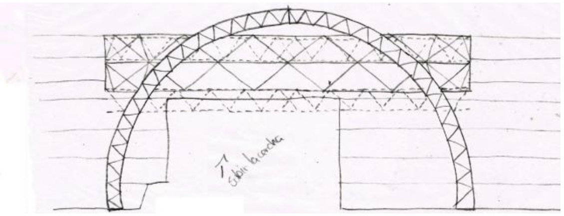


Figure 6
Second Iteration with Principal, Main and Legs Systems

This iteration gave more appropriate results, in terms of member sizes, and more room for design. The Principal system was changed from a post and beam to a tensile system. The Principal system is only supported on its ends, leaving the interior open. It boasts elements in tension for supporting the middle floor and elements in compression to support the roof and lower floor. (Figure 7)

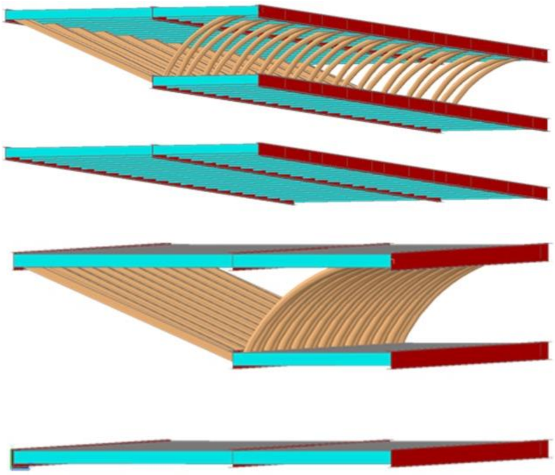


Figure 7
Principal System

The Main and Legs system have experience massive changes due to unfeasible elements. The Main system was holding large loads and didn't follow the theory about adaptability. The elements resulted too big, too necessary for the system to work and made the project feel anchored. The Legs system also had heavy elements, offering little or no chance for change.

The Main system had various examples and changes in design. This system tried to unify all 3 floors into one truss system which in turn would hang from the Legs system. Excluding the hanging idea, the fail was in the heavy loading and overly dense structure. The best way to create a less dense structure was to design custom sections and that didn't give the project its cost-effective result.

The Legs system actually was faring better than the Main, in terms of compression but not in tension when it came to using commercial sections. The system appears thin from a façade point of view, but flared outwards perpendicular to the building, increasing its bearing potential. To make the system work it would need to be dense and invade much of the usable site.

Even though the problems facing the Main and Legs system, the three system approach was still feasible, and a new idea was found doing historical research. The revised idea was inspired by the Gothic Cathedrals' flying buttress. The flying buttress transferred the vertical loads laterally towards buttresses with enough mass to convey the lateral forces to the ground. This idea worked by providing one tower on each end, to transfer the loads. However, the elements in the towers were too heavy and overcrowded making it complicated to construct and not appealing. (Figure 8)

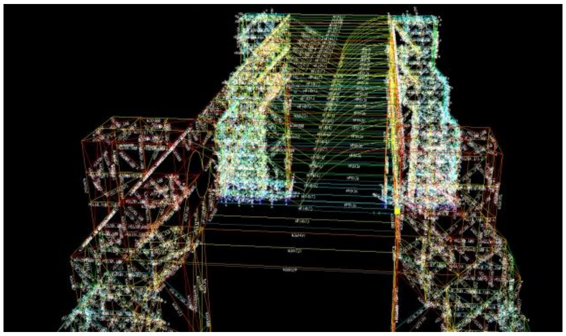


Figure 8
Flying Buttress Idea

The structure required heavy custom made parts and a higher structural density. I was able to find a suitable amount of density with diagonals, but the top part of the structure still needed densification and complicated joint connections.

The flying buttress idea had a good enough result to keep exploring. The concept evolved into, not a flanking buttress, but a parallel flying buttress. The project now focused on making the original design flanking towers into the buttresses.

The problem now was how to create a structural system within the towers without losing the open plan? How to make a buttress feel light and have enough redundancy that part of it could change on a whim? The answer was in the façade.

The idea of reinventing the glass louver system into an architecturally functional structural system and merging the Main and Legs system into the new buttress was studied. The louver elements would now be made of structural steel elements and the entire façade will now become an exoskeleton. This allowed an open plan on the inside and would provide the needed redundancy.

The louver system would be made of rectangular HSS horizontal elements that acted as both light/shade control and as lateral load support (old Main system). The vertical elements would be W sections closely spaced to act as a semi continuous footing system (old Legs system). The interaction between elements acted as a wall. This concept provided enough redundancy and consistency at the same time that the entire façade could be rearranged in different patterns. Designing the louvers in standard modules makes it's remodeling cost-effective.

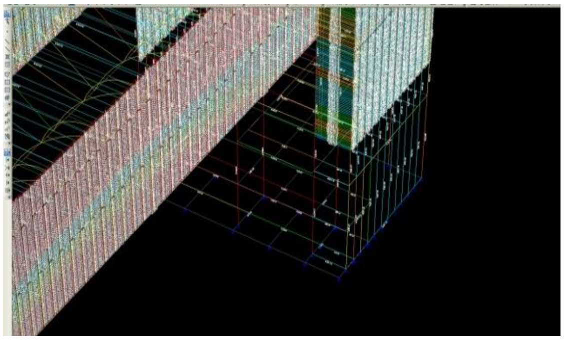


Figure 9
Original Façade

The first try was carried out using the original architectural façade which substituted the louvers for straight sections at the bottom and integrating the façade shear walls with the entire building supported on the subfloor. (Figure 9) This caused the structure to be unstable and contain heavy custom made columns at the bottom. The louver system, interior columns and beams could barely hold the loading of the truss. The louvers needed a better loading path without interruptions.

A design decision was made to extend the louvers all the way to the ground. (Figure 10) This will increase the redundancy ratio in the building and provided a unified loading path towards the ground. Another design decision was to incorporate extra shear walls to substitute the interior columns. The original shear walls were perpendicular to the building's longitudinal axis and following this principal, all perpendicular structures would be shear walls. These walls help with the earthquake loading and also as an anchor for the louver system on the perpendicular direction.

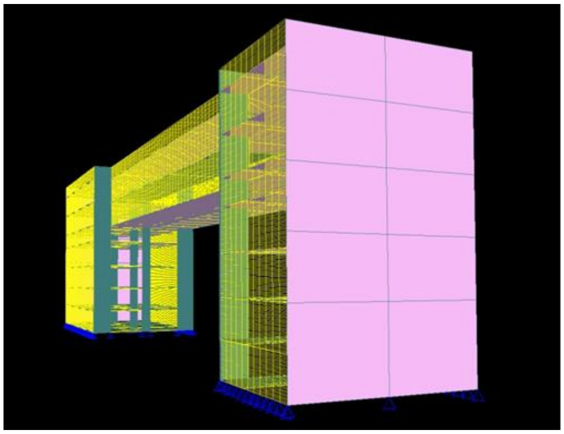


Figure 10
Final Proposal

The elements in the louver system are overdesigned due to the architectural requirement and their dual function, resulting from the synthesis between architecture and structural design.. However, this proves effective when eliminating, substituting or even amplifying the building as a whole or per parts. The aesthetic of the architectural thesis proved to be the most effective way to respond to the structural needs of the building.

The Materials

The primary materials are reinforced concrete and structural steel. The secondary materials are gypsum board, masonry and wood. Third order materials are glass, sound proofing, and insulating materials.

The reinforced concrete will be used on floor slabs and shear walls. Footing design is outside the scope of this project. The shear walls will be the main structural element on the short sides of the building, the east and west façade. The walls will cover the entire height providing the shear resistance necessary for the new building. The emergency stairs and elevator core, which are elements used for shear resistance for the new building are not covered in this project and have been redesigned.

The floors will be designed as diaphragms and will be solely in change of acting and dissipating the shear forces of the lateral loads. A floor analysis was made to create a modular reinforced concrete design in which various floors have the same properties providing an easier way to rebuild.

The structural steel will be used as the main loading system. The steel elements are varied and some depend only on the architectural vision of the original design. W sections will be used in columns and beams. Square HSS will be used as tensile elements for the main long span truss. Circular HSS sections will also be used as tensile elements for the main long span truss for safety and aesthetic reasons. Rectangular HSS will be used as part of the main loading system to achieve both the aesthetic design and as key components in the redundancy modular system. All compression members of the truss will be W sections.

The secondary and third order materials are considered only as dead loads. The glass elements are part of the facade system and will be the ones receiving the wind pressure.

The project will unify all dead loads and apply them equally on all floors. Hence the ability of the building to accommodate future needs without worrying about the dead load requirements.

ANALYSIS

All loads are the highest conceivable by code to ensure that future uses won't have problems.

The Dead Loads

The dead loads taking into account where those corresponding to the primary structure with an approximate of secondary and third structural elements. The primary structure is composed of the reinforced concrete slabs and steel beams, which will be affecting the design of the columns and louver system. Included in this system are the finishes for the flooring, which may be categorized as a third component however it is an integral part of the architectural proposal. Finishes for the walls, columns and louver system will be imposed on the system itself. The secondary elements adding weight will be masonry, gypsum and wood partitions, however only the weight of the masonry will be added as is the heaviest of the set and assuming half occupancy of the floor space as max coverage. The third structural elements are mechanical, electrical, ceiling and insulating materials, being the ceiling finishes as the possible heaviest of them with half occupancy of the floor space as max coverage.

- Reinforced Concrete = 72 psf
- Marble or Terrazzo finish = 33 psf (16.5 psf)
- Suspended metal lath w/ gypsum ceiling finish = 10 psf (5psf)
- Masonry (105pcf) 8in = 75 psf (37.5 psf)
- Wood Decking 3in wall finish = 8 psf
- Steel beams overall assumed weight = 200 psf (100 psf)
- **Total loads are:** Floors = 131psf; Walls = 8psf; Beams = 100psf

The structural floor slabs where designed using these weights. The average weights where used for overall assumed weight of the building for earthquake and shear analysis.

The Live Loads

There was a design decision for what would be the highest possible and credible live load that could occur in the higher levels. The largest live load belonged to a boiler room with 300 psf, however it was unlikely and not that cost-effective to have a boiler room on floors not constructed over soil. The second highest then became the primary target for analysis. The heavy storage room with 250 psf is the largest live load that the diaphragms of the building will have to react to. Since the program demands some of these heavy storage rooms on floors above ground level, it was imperative that not only the lower levels could cope with this load, but also upper levels that could be provided later on hand as well.

The Wind

The wind study was performed on all four sides of the new building assuming that the louvered system, being closely spaced (6 in center to center), will act a solid wall. Being a rectangular building, the wind study was performed to recreate the possible push and suction on the larger sides of it.

The wind study showed that the largest surface wall pressures occurred from the south-western side by a small margin over the north-eastern side. However, the suction pressures for the longest walls weren't far behind, being 9% one below the other. The largest ceiling surface pressure occurred when the wind impacted the short walls. For the project, the surface pressures used will be those from the wind perpendicular to the large walls and the ceiling pressures will be those parallel from the large walls. A wind profile was also created for the location.

The wind variables are: Wind speed = 162 mph; Building category = 2; Importance factor = 1; Exposure = B; Type = Enclosed; Length = 365.5 ft; Width = 76.5 ft; Height = 108 ft; kd = .85; GCpi = +/- .18.

The kzt Topographical factor was calculated assuming a 2-D ridge behavior and also using a speed up behavior due to the fact the building is on a slope where the wind will speed up. Kzt = 1.05659.

Kz and Kh factors were calculated using the formulas in ASCE 7-05.

The fundamental period using structure type and tempering it with earthquake classification for the site is: T = .6818 seg, F = 1.466706 hertz.

The Gust factor coefficient used was that of a flexible structure, since the period was less than 1. G = .849178.

Cp values for walls were assumed when the wind is perpendicular to the longest wall. Cp values for roofs were assumed when the wind was parallel to the longest wall. Cp: ww=.8, lw=-.2, sw=-.7; Cp: 0-h=-.9/-.18; h-2h=-.5/-.18; >2h=-.3/-.18.

The wind study showed the gradual increase in surface pressure from a height of 15 feet to a height of 110 feet by 1 foot of was to be from 33.68097 lb/ft^2 to a maximum of 51.30593 lb/ft^2. A roof suction from -72.25135 lb/ft^2 making the roof have a maximum suction pressure of -12,538.2 lbs overall.

The Earthquake

The earthquake effects were analyzed on two different directions resulting in the north-south directions the ones more critical. An estimated weight of the building was used using a combination of concrete flooring and steel beam and columns per floor.

The fundamental period using structure type and site classification: T = .6818 s, F = 1.4667 Hz.

A design spectrum for the soil was created using the codes variables: Site Class = D; Ss = .9, S1 = .31; MCE = .41, TL = 12.

Using the short spectrum (Ss) we get the values for Fa= 1.14 and Fv= 1.78. With these values we can obtain SMs= 1.026g and SM1= .5518g. Obtaining the values of SDs= .684g and SD1= .36787g needed to create the design spectrum of the site.

This spectrums where used in the equivalent lateral force method used to analyze the structure, obtaining a collective base shear of 4,512,615 lb (4,512 kips). This value was then distributed on the floors permitting the calculation of the story drift.

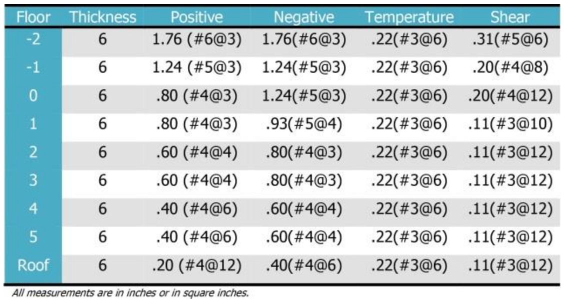
SUMMARY OF THE STRUCTURAL DESIGN

The following is a summary of all the structural parts of the building. Manual calculations where done and compared to SAP.

- **Steel Anchors:** Stud diameter: .75 in and use: 7 per secondary 18 ft beam.
- **Diaphragms:** Slabs where designed with a span of 9ft following the ideal of easier and cost-effective remodel.

Table 1

Diaphragms



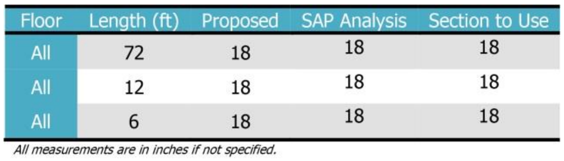
Floor	Thickness	Positive	Negative	Temperature	Shear
-2	6	1.76 (#6@3)	1.76(#6@3)	.22(#3@6)	.31(#5@6)
-1	6	1.24 (#5@3)	1.24(#5@3)	.22(#3@6)	.20(#4@8)
0	6	.80 (#4@3)	1.24(#5@3)	.22(#3@6)	.20(#4@12)
1	6	.80 (#4@3)	.93(#5@4)	.22(#3@6)	.11(#3@10)
2	6	.60 (#4@4)	.80(#4@3)	.22(#3@6)	.11(#3@12)
3	6	.60 (#4@4)	.80(#4@3)	.22(#3@6)	.11(#3@12)
4	6	.40 (#4@6)	.60(#4@4)	.22(#3@6)	.11(#3@12)
5	6	.40 (#4@6)	.60(#4@4)	.22(#3@6)	.11(#3@12)
Roof	6	.20 (#4@12)	.40(#4@6)	.22(#3@6)	.11(#3@12)

All measurements are in inches or in square inches.

- **Shear Walls:** The eastern and western facades are all full shear walls with no openings.

Table 2

Shear Walls



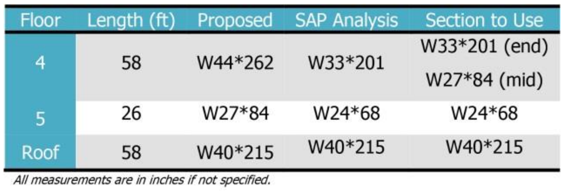
Floor	Length (ft)	Proposed	SAP Analysis	Section to Use
All	72	18	18	18
All	12	18	18	18
All	6	18	18	18

All measurements are in inches if not specified.

- **Truss Static Analysis:** Bars: 13, Reactions: 8, Joints: 27.
- **Truss Elements (Horizontal):** The design of the truss would have been lighter with what SAP proposed, a section W40*183, but due to height limitations a heavier section was used. The maximum was 34 inches or close to this in order to permit fluent travel on the floor below on floor 4.

Table 3

Truss Horizontal Elements



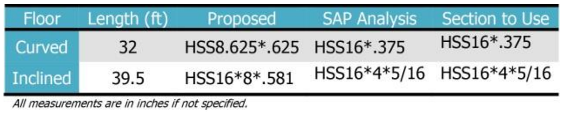
Floor	Length (ft)	Proposed	SAP Analysis	Section to Use
4	58	W44*262	W33*201	W33*201 (end) W27*84 (mid)
5	26	W27*84	W24*68	W24*68
Roof	58	W40*215	W40*215	W40*215

All measurements are in inches if not specified.

- **Truss Elements (Diagonals):** These where originally chosen for aesthetic purposes. The inclined element had to be in a 2:1 ratio or similar; a HSS16*8 was chosen, but the design benefited with a 4:1 ratio. The curved truss element was going to be half of the inclined element, but due to bending and shear forces it needed a bigger section. The same width of HSS inclined section and a HSS16 was chosen.

Table 4

Truss Diagonal Elements



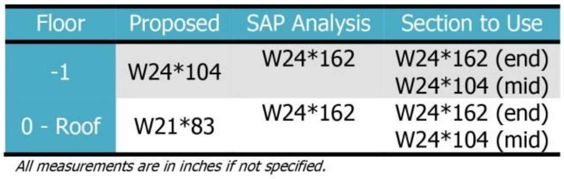
Floor	Length (ft)	Proposed	SAP Analysis	Section to Use
Curved	32	HSS8.625*.625	HSS16*.375	HSS16*.375
Inclined	39.5	HSS16*8*.581	HSS16*4*5/16	HSS16*4*5/16

All measurements are in inches if not specified.

- **Secondary Beams:** There are manual floor by floor calculations for designing the secondary beams, but the end decision was to use a single section for repetitiveness purposes and reuse potential. This forced a division of the floor plans in 3 zones and each zone has a minor and a mayor section. Mayor sections are used on the locations closest to the truss system while the minor sections are used on the rest of the floor.

Table 5

Secondary Beams 36 ft Zone 1

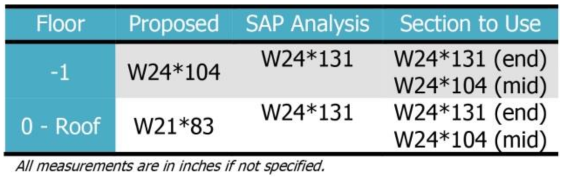


Floor	Proposed	SAP Analysis	Section to Use
-1	W24*104	W24*162	W24*162 (end) W24*104 (mid)
0 - Roof	W21*83	W24*162	W24*162 (end) W24*104 (mid)

All measurements are in inches if not specified.

Table 6

Secondary Beams 36 ft Zone 2

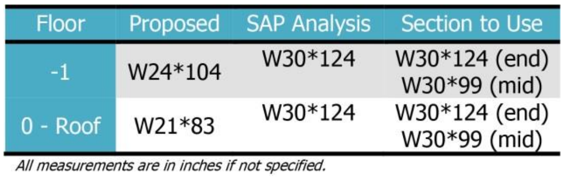


Floor	Proposed	SAP Analysis	Section to Use
-1	W24*104	W24*131	W24*131 (end) W24*104 (mid)
0 - Roof	W21*83	W24*131	W24*131 (end) W24*104 (mid)

All measurements are in inches if not specified.

Table 7

Secondary Beams 36 ft Zone 3



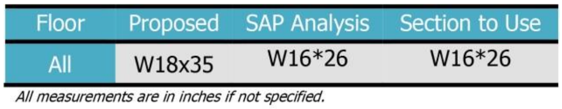
Floor	Proposed	SAP Analysis	Section to Use
-1	W24*104	W30*124	W30*124 (end) W30*99 (mid)
0 - Roof	W21*83	W30*124	W30*124 (end) W30*99 (mid)

All measurements are in inches if not specified.

- **Primary Beams:** There are 4 different lengths in primary beams due primarily to original programmatic design. Even though this might seem a bit restrictive, the open plan offered compensates for this.

Table 8

Primary Beams 17 ft

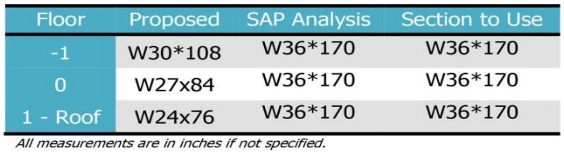


Floor	Proposed	SAP Analysis	Section to Use
All	W18x35	W16*26	W16*26

All measurements are in inches if not specified.

Table 9

Primary Beams 31 ft

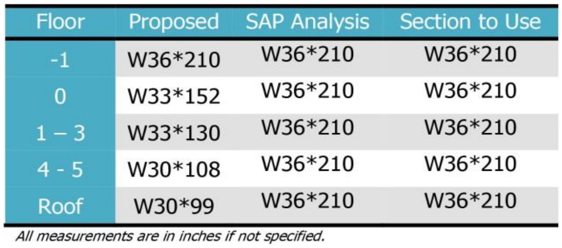


Floor	Proposed	SAP Analysis	Section to Use
-1	W30*108	W36*170	W36*170
0	W27x84	W36*170	W36*170
1 - Roof	W24x76	W36*170	W36*170

All measurements are in inches if not specified.

Table 10

Primary Beams 48 ft

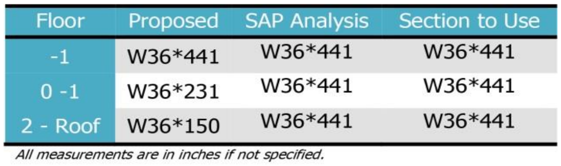


Floor	Proposed	SAP Analysis	Section to Use
-1	W36*210	W36*210	W36*210
0	W33*152	W36*210	W36*210
1 – 3	W33*130	W36*210	W36*210
4 - 5	W30*108	W36*210	W36*210
Roof	W30*99	W36*210	W36*210

All measurements are in inches if not specified.

Table 11

Primary Beams 60 ft



Floor	Proposed	SAP Analysis	Section to Use
-1	W36*441	W36*441	W36*441
0 -1	W36*231	W36*441	W36*441
2 - Roof	W36*150	W36*441	W36*441

All measurements are in inches if not specified.

- **Façade Elements (Horizontal):** The horizontal façade elements comprises both the main connecting beams, called the Horizontal Master beams only used where the diaphragm connects to the façade system and the louvers. The Horizontal Master beams where conceived to have exactly 36 inches in height, mainly W36*160. However, it was more beneficial for the structure to go with a slightly lower weight maintaining roughly the same height and a W36*135, which is 35.6 inches tall. The louvers where always conceived to be 2 inches in thickness with a 12 inch depth. Even though an HSS8*2 would suffice for the project, the aesthetic design wouldn't be accomplished in the inside.

Table 12
Horizontal Façade Elements

Floor	Length (ft)	Proposed	SAP Analysis	Section to Use
All	4.25	HSS12*2*5/16	HSS12*2*3/16	HSS12*2*3/16
All	Varies	W36*160	W36*135	W36*135

All measurements are in inches if not specified.

- **Façade Elements (Vertical):** The columns for the louver system where also designed with a specific profile of 36 inches. However, it was more beneficial to have 36 in profile on the lower levels and have a slightly less profile on the upper levels. There was a necessity to provide more strength on the elements that connected the internal shear walls to the façade and those elements were labeled Primary. Only 6 of these Primary Columns are on the façade not affecting the aesthetics.

Table 13
Vertical Façade Elements

Floor	Length (ft)	Section Proposed	SAP Analysis	Section to Use
Bottom Floors	Varies	W36*160	W36*160	W36*160
Upper Floors	Varies	W36*160	W33*118	W33*118
Primary	Varies	W36*170	W36*182	W36*182

All measurements are in inches if not specified.

SUMMARY OF CONCLUSIONS

While the structural design had some limitations due to aesthetic or height restriction reasons, the overall structure proves that one simple redundancy system can supply enough structural strength and stability for continued reuse by providing an open space plan with possibilities for expansion. The louver system provides both aesthetic and structural function, being an integral part of the building. This, however, doesn't mean that an efficient redundancy system only relies on the façade itself. The project proved that a simple system, with enough repetition and consistency can be located anywhere on the structure and give it reusability and longevity.

The project also proved that a redundancy system is capable of simplifying the need to redesign structure in order to reuse a building. The system supplies the strength to design minimal internal structure that won't compromise usable space. Being a modular system the parts are interchangeable and easy to replace.

The great achievement of this redundancy system comes from the ability to span large spaces without large infrastructure. The envelope of the truss element served as a critical component to move the loads to the parallel flying buttress system. The truss with its tensile style system is also an achievement. The loads travel by tension alone on the middle of the triangular truss design and by compression only on the top chord. This design boasts an open plan with minimal internal structure that occupies usable space. The design proves aesthetically pleasing and provides an open plan on the bottom chord of the truss, once again using a redundant system to work as both architecture and structure. (Figure 11 &12)

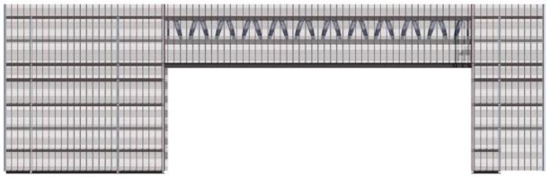


Figure 11
Final Proposal

The project also proves that future expansions and or extensions either upwards or sideways are possible if desired at a very cost-effective manner. Given the nature of the modular system, the overabundant strength of the structure and its open spatial configuration, future programs can maximize the use of the structure. The possibilities for the future are endless.

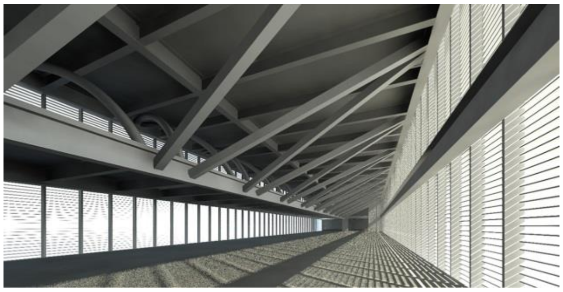


Figure 12
Large Open Space Design

REFERENCES

[1] Delgado, M. D., “Perpetual Disease: The Constant Erasing of Architecture”, Unpublished.

[2] Seung-Han, S. and Wen, Y., *Structural Redundancy of Dual and Steel Moment Frame Systems under Seismic Excitation*, 2000. [Online]. Available: https://www.ideals.illinois.edu/bitstream/handle/2142/14247/SRS-31.pdf?sequence=2 File: Chapter 6.

[3] Posters, H., *Reliability Engineering - Part 13* [Online]. Available: http://d577289.u36.websitesource.net/attach_files/ReliabilityEng-Part13.pdf.

[4] Pierre, *Active or Passive Redundancy*, 2012. [Online] Available: http://broadcast-it.com/e107_plugins/content/content.php?content.28.