Energy in Form

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Architecture In Architecture

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Abstract

This thesis is a study of architectural form in relation to energy.

Energy performance is rooted in form. Overall performance in the practice of architecture includes necessarily consumption as a form constraint.

The term energy in this body of work relates to the social circumstance that the current state of the environment imposes on all facets of life, including how our buildings contribute to the anthropogenic warming of the earth's atmosphere. Humans are consumptive and so our buildings, a product of our work, are inherently consumptive as well. The challenge is to design environments that stimulate responsible actions by considering energy consumption throughout the design process. This thesis proposes that an architecture which responds with significance explores the energy-in-form to make a contribution to the current condition in which we live.

On an abstract level, formal elements of negation and the condition of boundary are explored in relation to energy. On a more factual level, the impact of energy on site orientation, shading, and in-between zones are tested. Form in the study of the proportions of the Maison Carrée is expressed in the process of making concrete objects and the regulating geometry and formal conditions of the final Cornerstore building design.

Energy in Form

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The Cornerstore

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View from the north at the corner of MLK Ave and Milwauke Pl.

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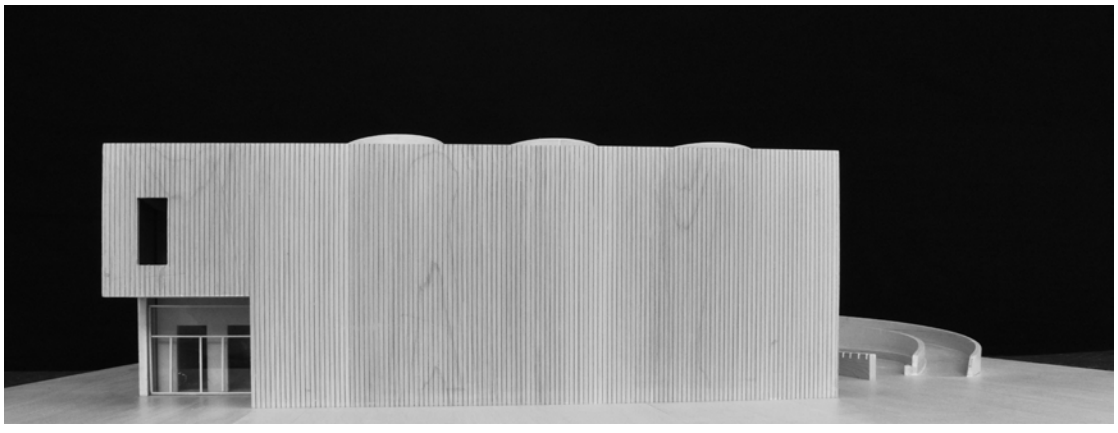

04.

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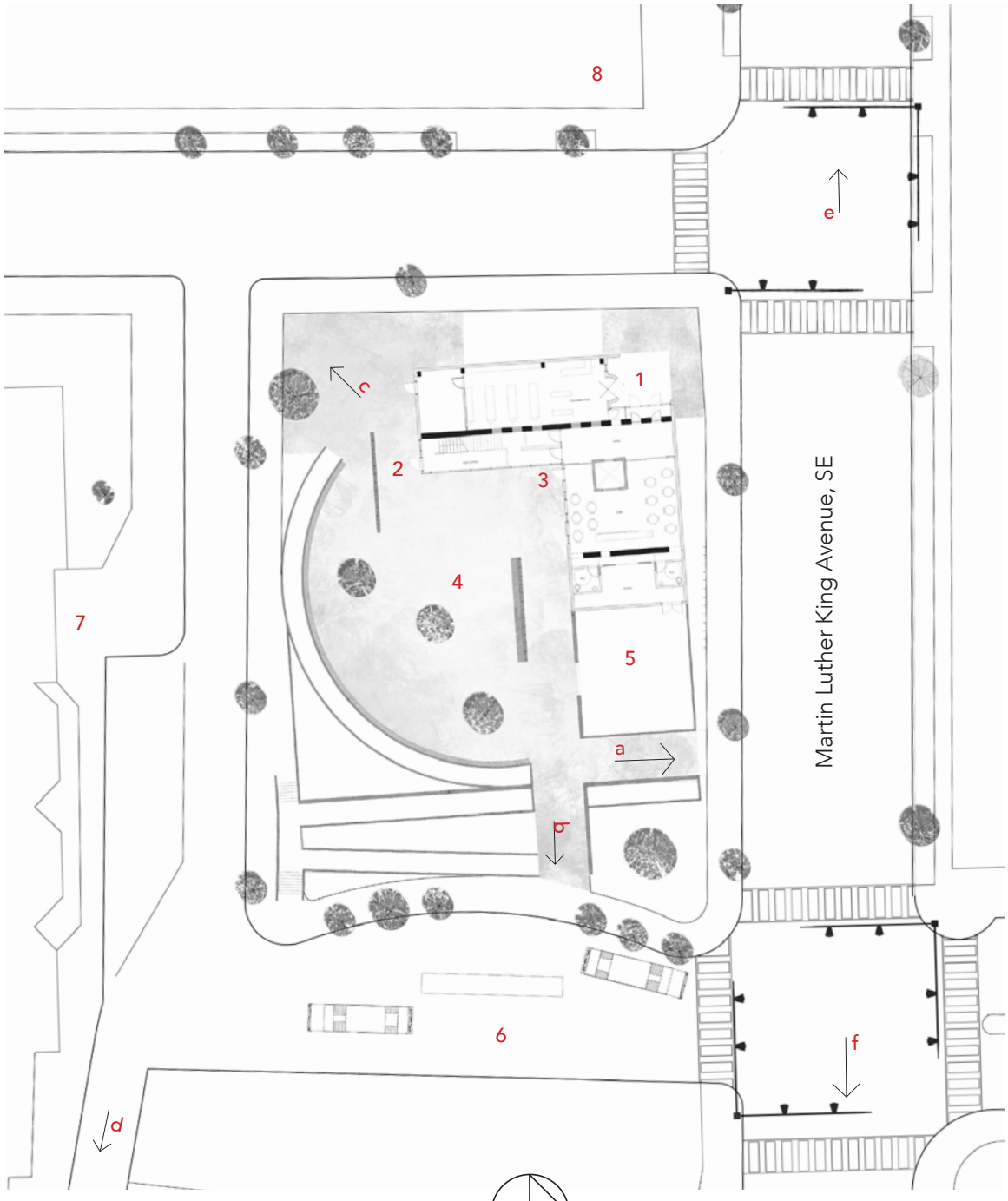
06.

Elevations from the top: North, East, South, West



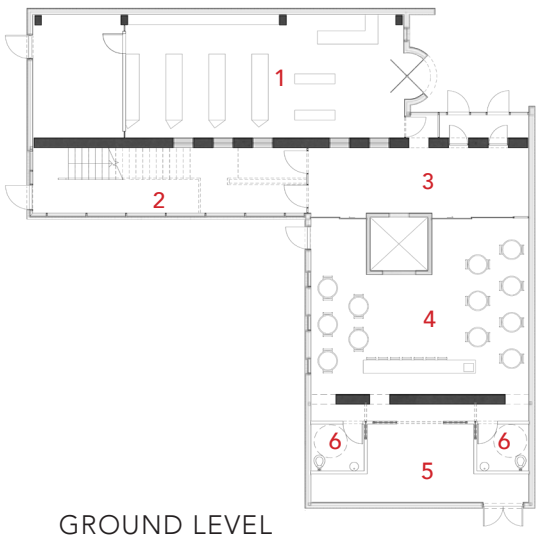
07. Site with Ground Level floor plan

1. North Entrance to Convenience Store and Lobby
2. West Entrance through Stair/Corridor
3. West Entrance to Cafe
4. Plaza
5. Storage area under the outdoor Patio
6. New Bus Stop
7. Entrance to Friendship Charter Elementary
8. Entrance to Friendship Charter Highschool

a → To MLK Ave.
b → To New Bus Stop
c → To Schools
d → To Residential and some Retail
e → To DC
f → To Maryland

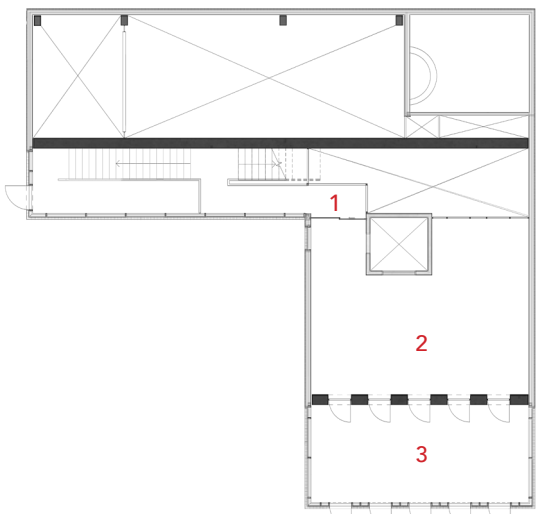
THE CORNERTSTORE

From a typical DC corner store, the program expands to include a cafe, two art gallery spaces, and an outdoor patio and plaza. The corner store as a place of gathering is expanded to better provide social connection for the surrounding community. A plaza is protected by the building to the north and the walls supporting ramps leading to the second level patio to the south, east, and west. The walls shelter the plaza from the busy avenue to the east and defines a distinct boundary between the site and the two public charter schools to the north and west. To the south, a new bus stop allows for a safe drop off and pick up of students who use public transportation to get to school and for commuters alike that take the bus to the metro or directly downtown. The corner site is proposed as a neighborhood hub, a space in-between the community and the city.



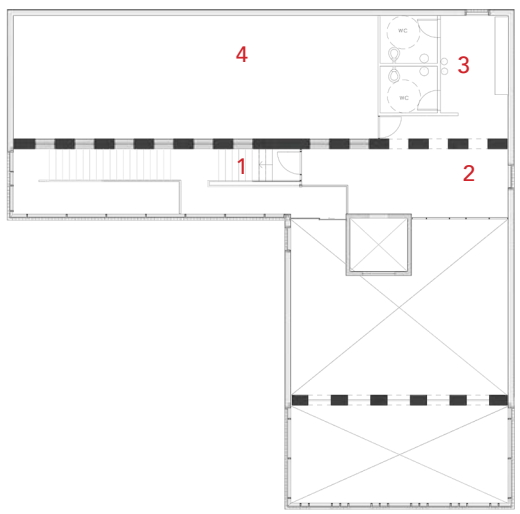
GROUND LEVEL

1. Convenience Store
2. Stair/Corridor
3. Lobby
4. Cafe
5. Kitchen
6. Restrooms



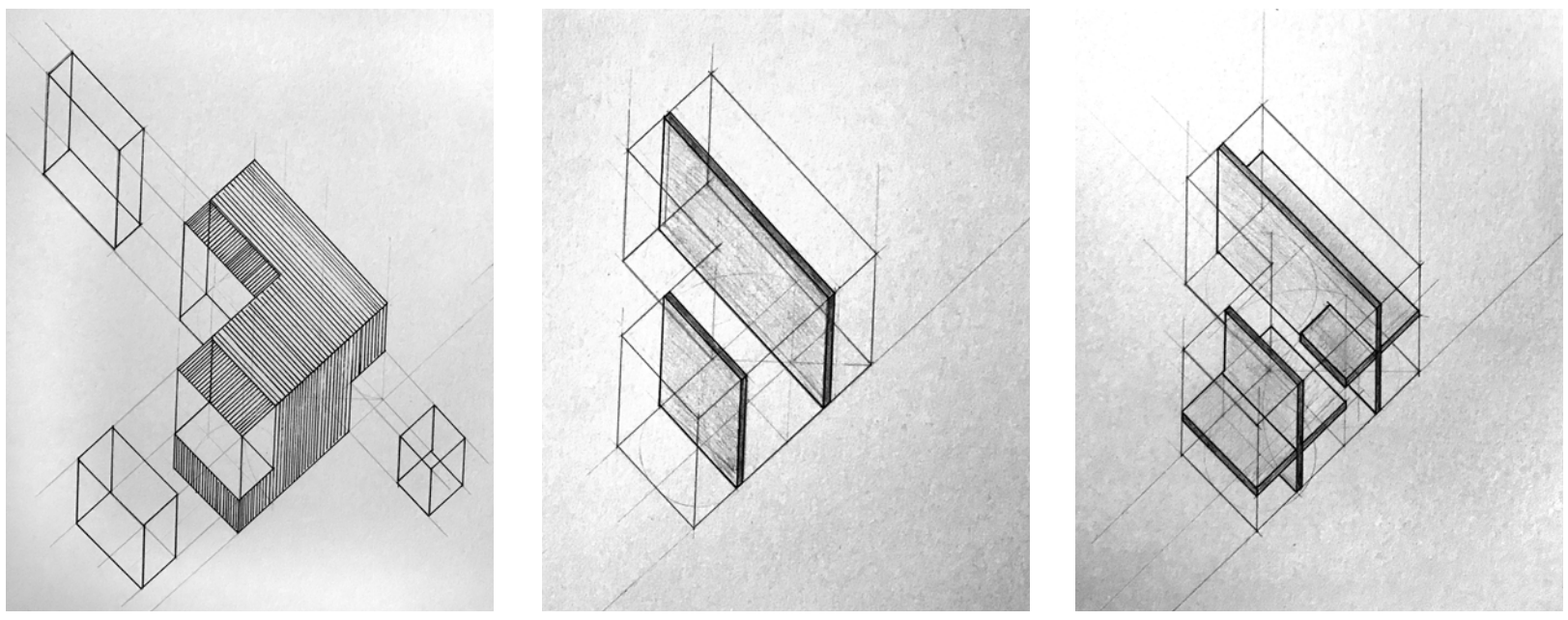
LOWER LEVEL

1. Entrance to Lower Level
2. Lower Level Gallery
3. Lower Level Enclosed Patio



UPPER LEVEL

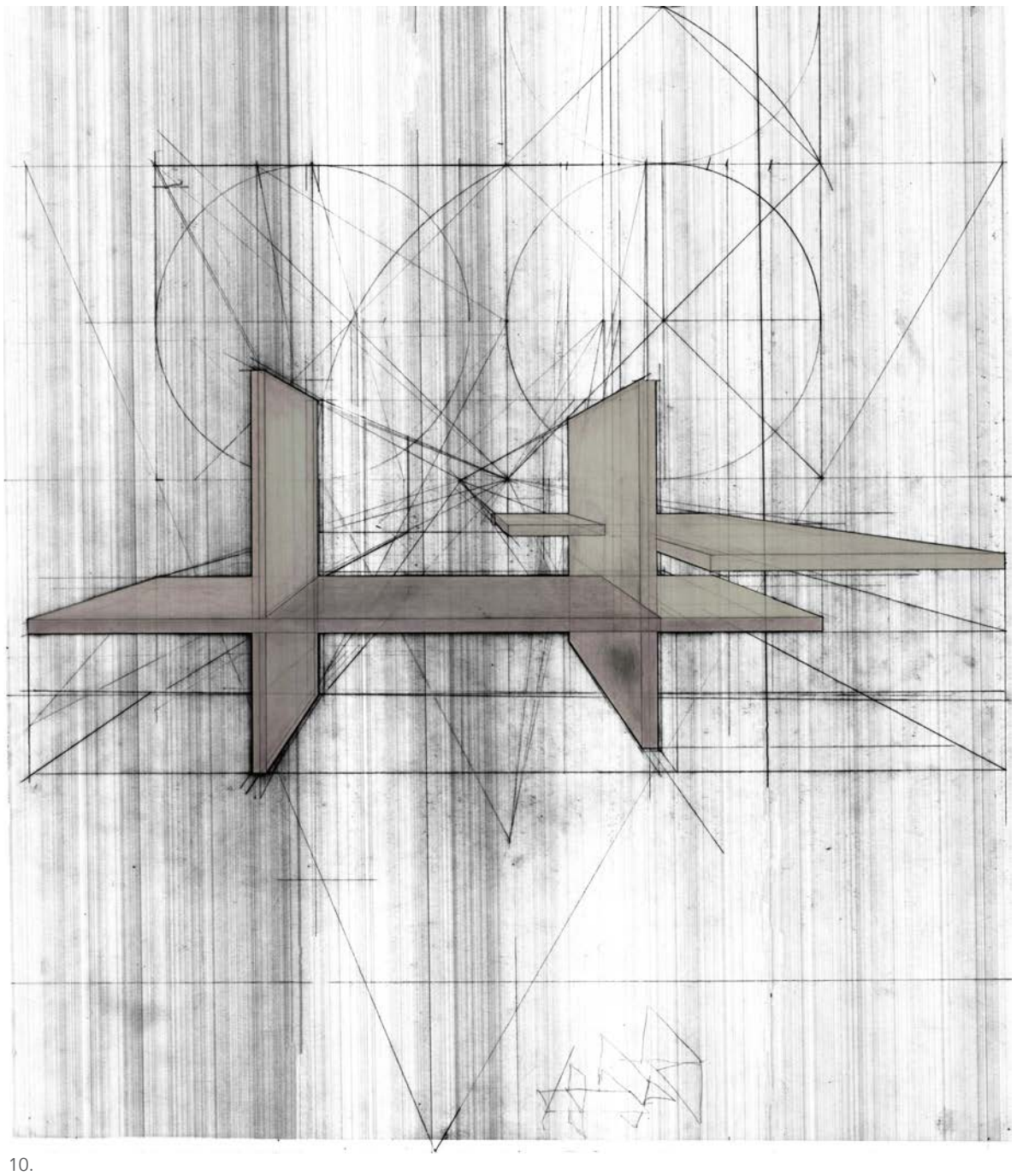
1. Entrance to Upper Level
2. Upper Level Lobby
3. Bathrooms/Coat Room
4. Upper Level Gallery



09.

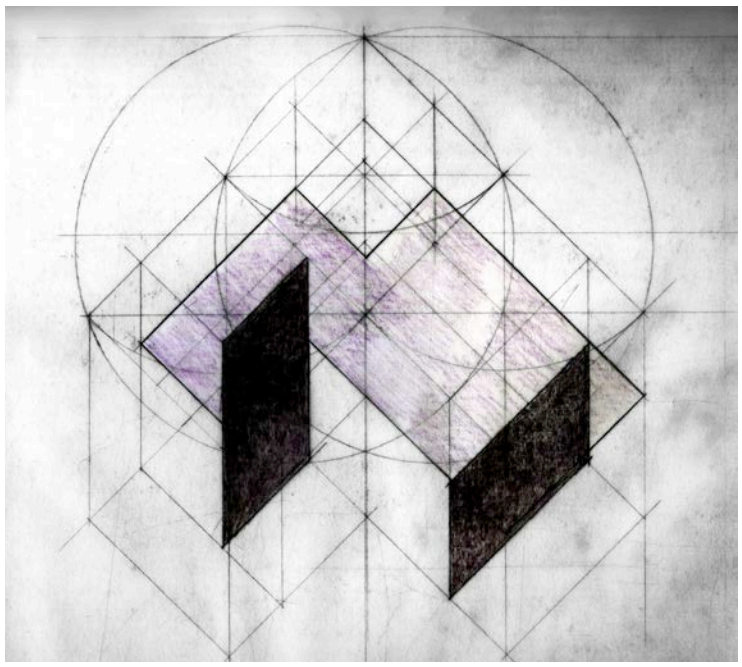
Three formal acts:

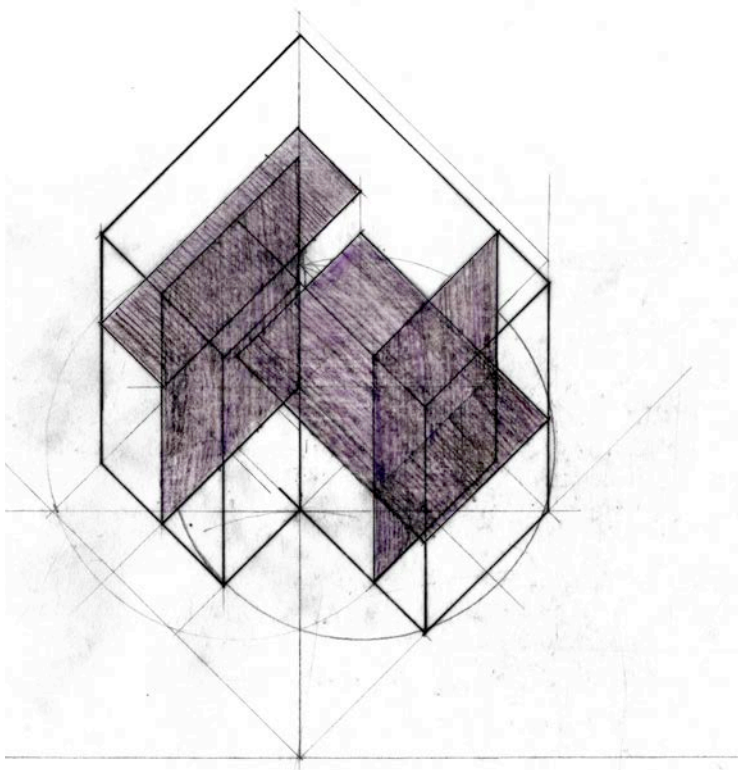
1. Subtract volume from L shape form, which in turn become the spaces between.
2. Divide the conditioned and the in-between with the mass of two interior concrete walls.
3. Define floors to complete the interior structure independent from the building envelope.



10.

Perspective drawing of concrete structure



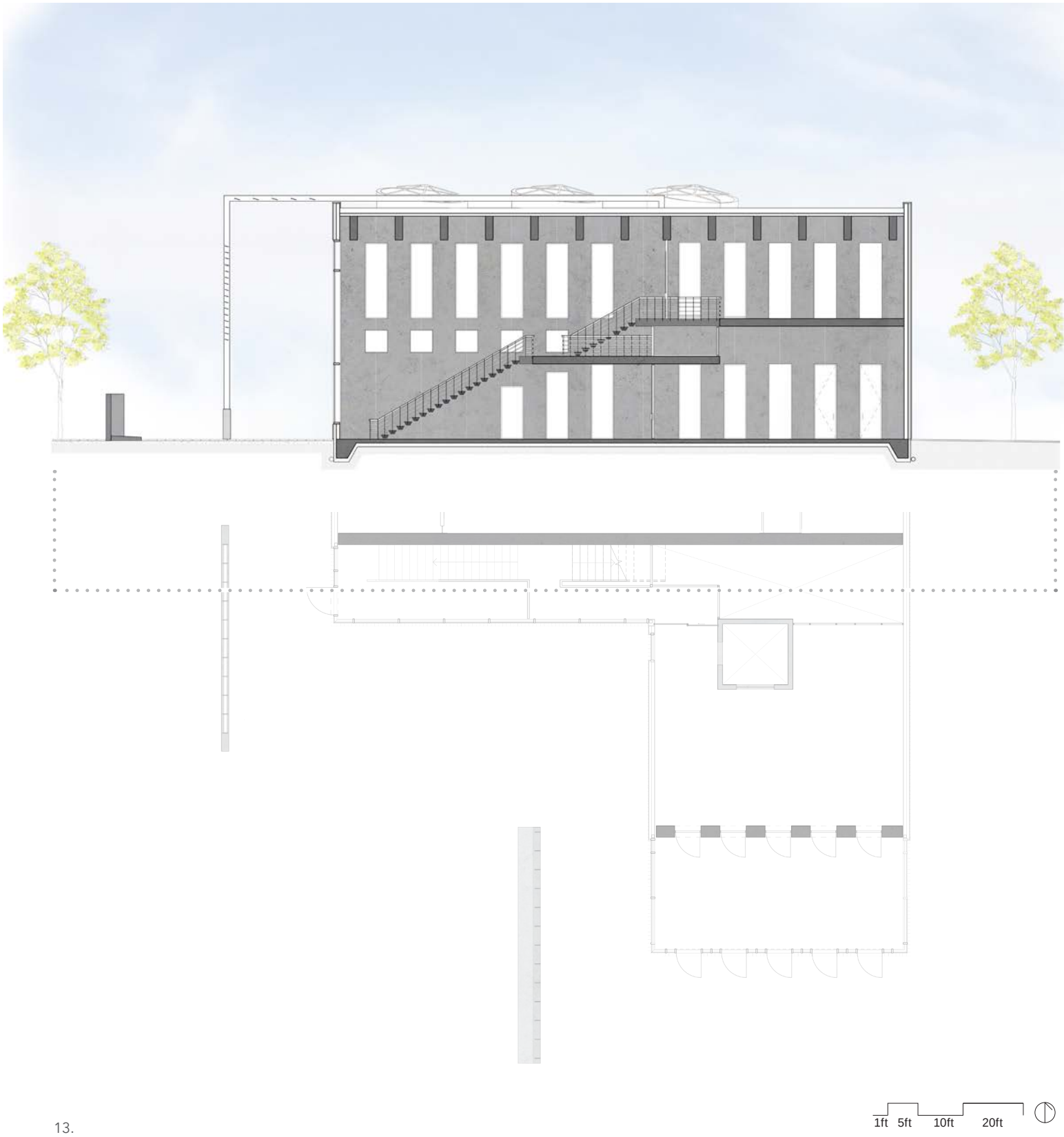


11.

Axonometric drawings of interior space organization

12.

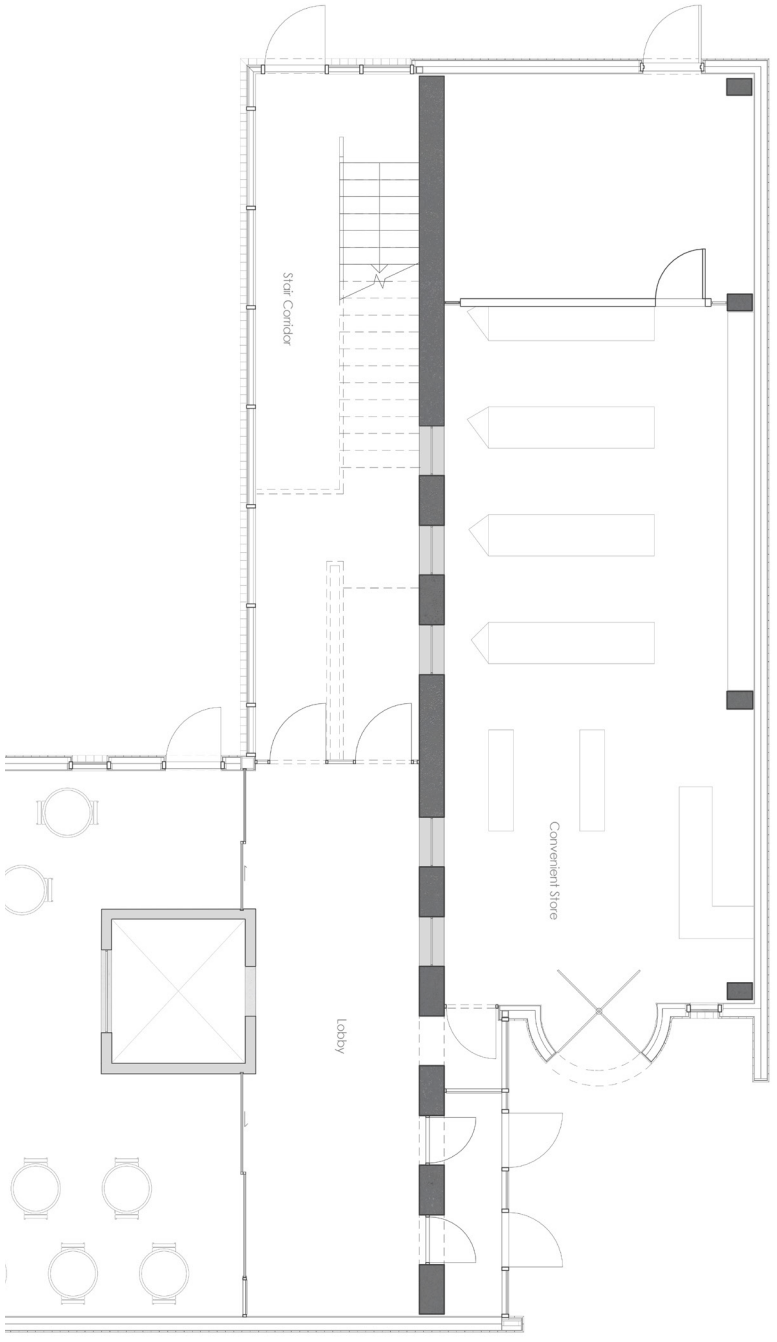
Section and plan showing the concrete wall that divides the cafe seating area from the kitchen/restrooms on the ground floor and the lower level gallery from the patio on the lower level.

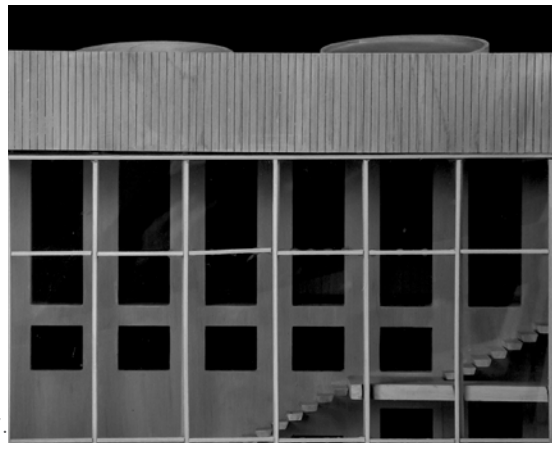


13.

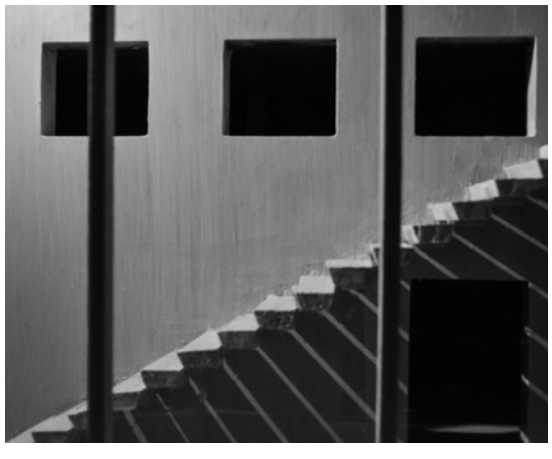
Section and plan showing the concrete wall that divides the convenience store and upper level gallery from the stair/corridor and lobby spaces.

14.,15.

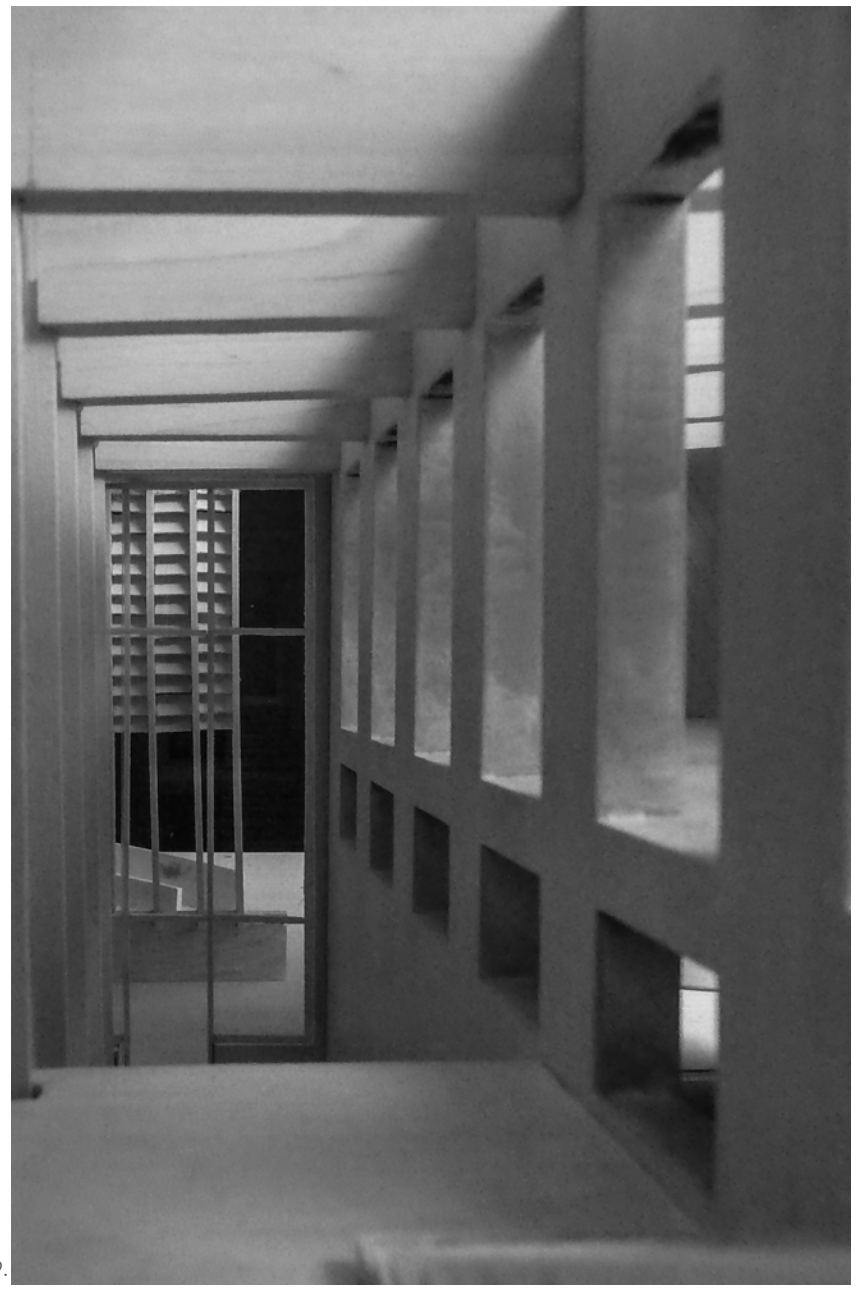




16.,17.



A concrete wall divides the convenience store from the stair/corridor. It is two feet thick and perforated with openings that illuminate the retail space with natural daylight and provide a visual connection between the interior spaces and to the activity of the exterior plaza. The thickness of the concrete provides an interior stabilized thermal mass to regulate the heat swings of the glazed stair/corridor.



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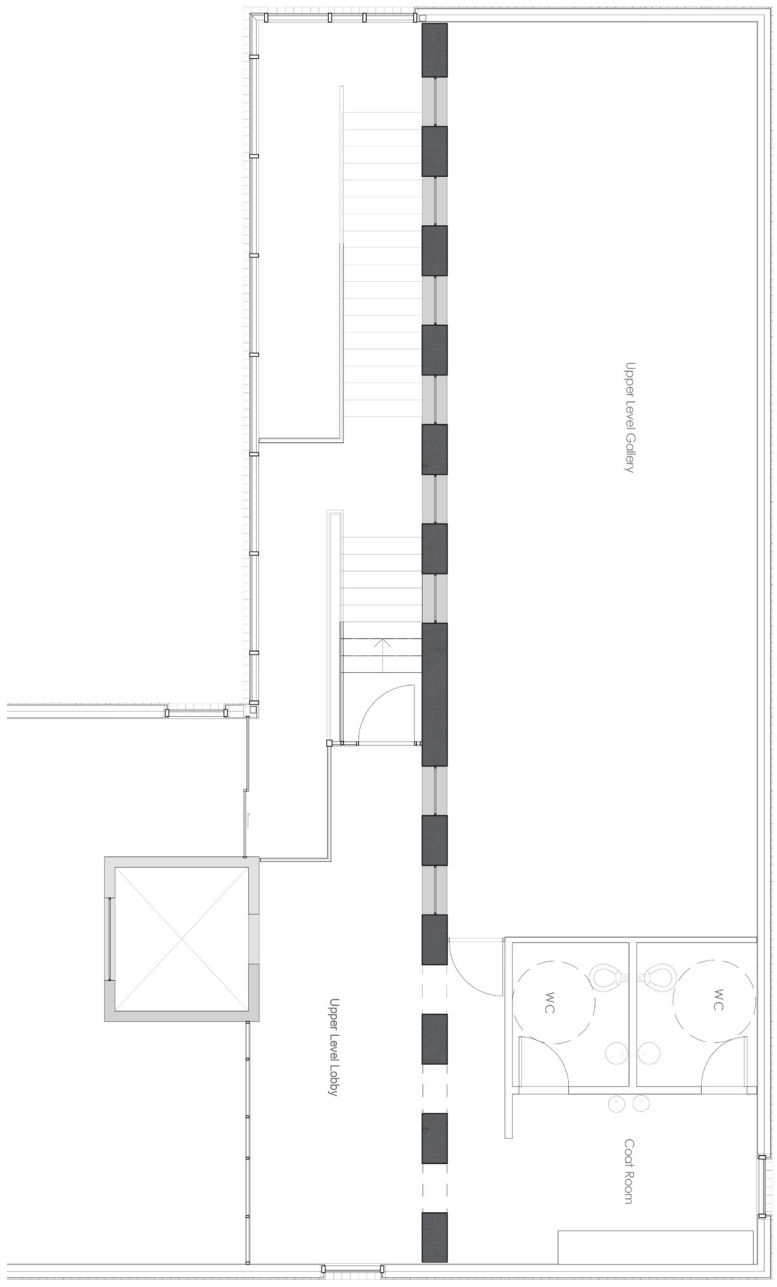

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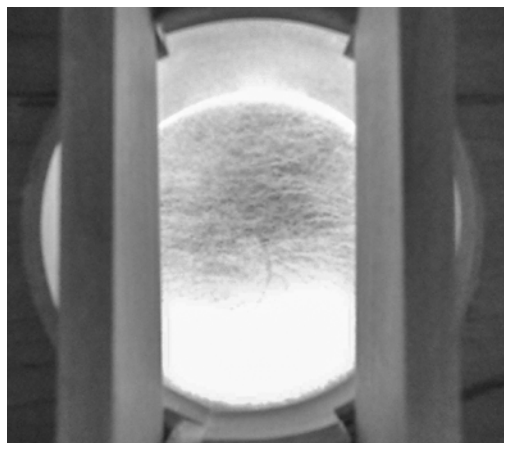
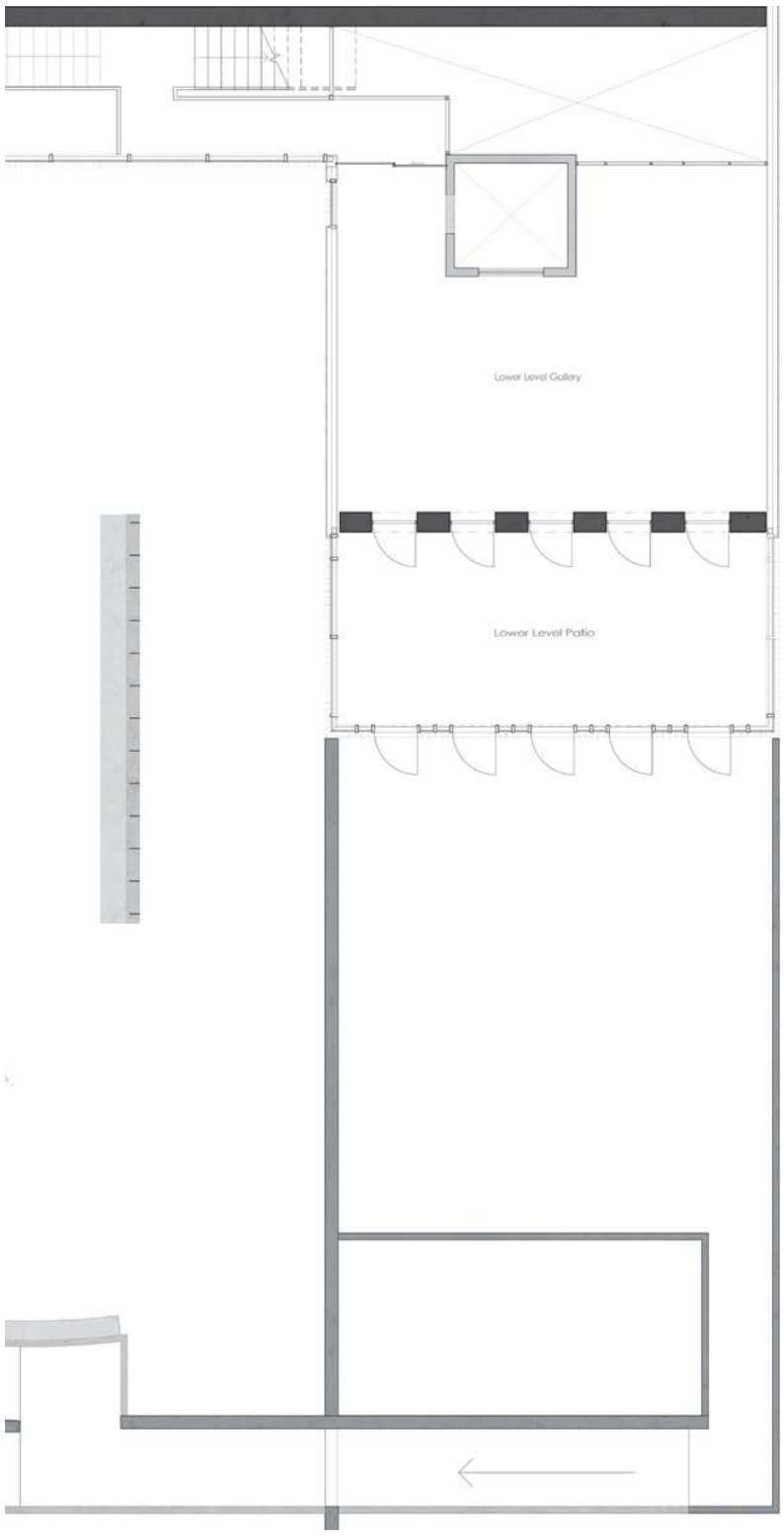


The stair/corridor connects the ground floor to the galleries on the lower and upper levels. Openings in the concrete wall provide indirect natural daylight to the upper level gallery and a visual connection to the exterior plaza. The upper level gallery is also illuminated by the three circular concrete skylights that rest on the concrete roof trusses. The north and west wall are uninterrupted for exhibitions use.

22.

23.,24.

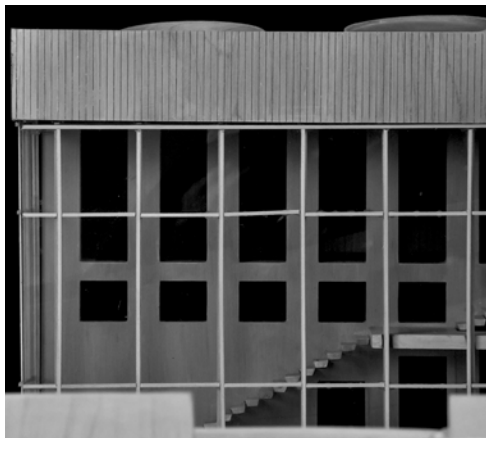
25.

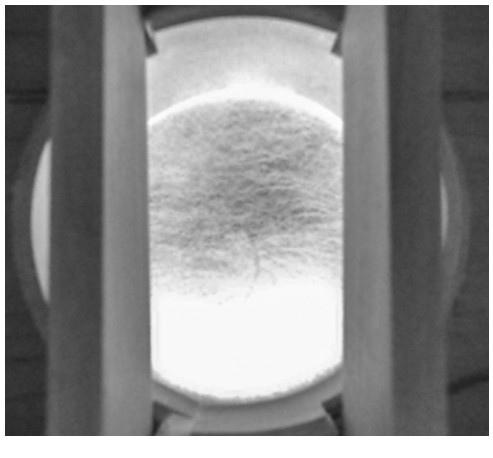


The lower level gallery is accessed from the stair/corridor, the elevator, and the lower level patio which opens onto the outdoor patio and ramp to the plaza. A concrete wall divides the gallery from the patio. It is also two feet thick and repeats the same rhythm of openings as the other concrete wall, allowing indirect daylight into the space through the patio. This gallery is also illuminated by the singular large concrete skylight. The east and west walls are uninterrupted for exhibition use.

26.,27.,28.

29.,30.,31.





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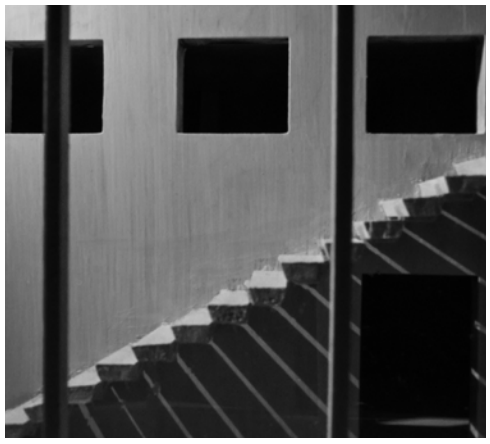

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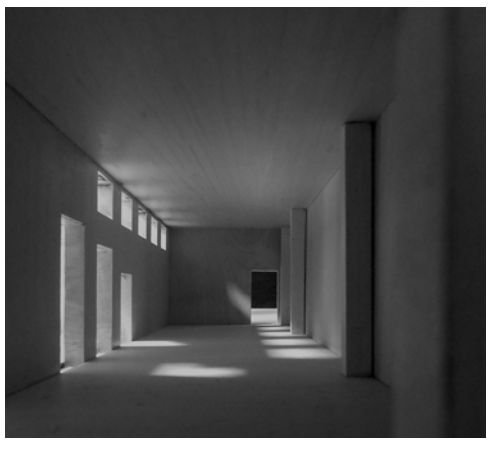
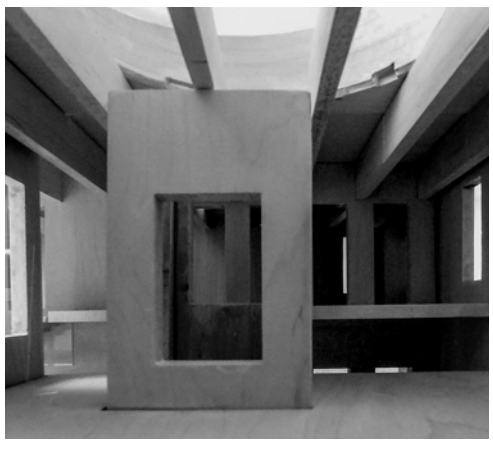
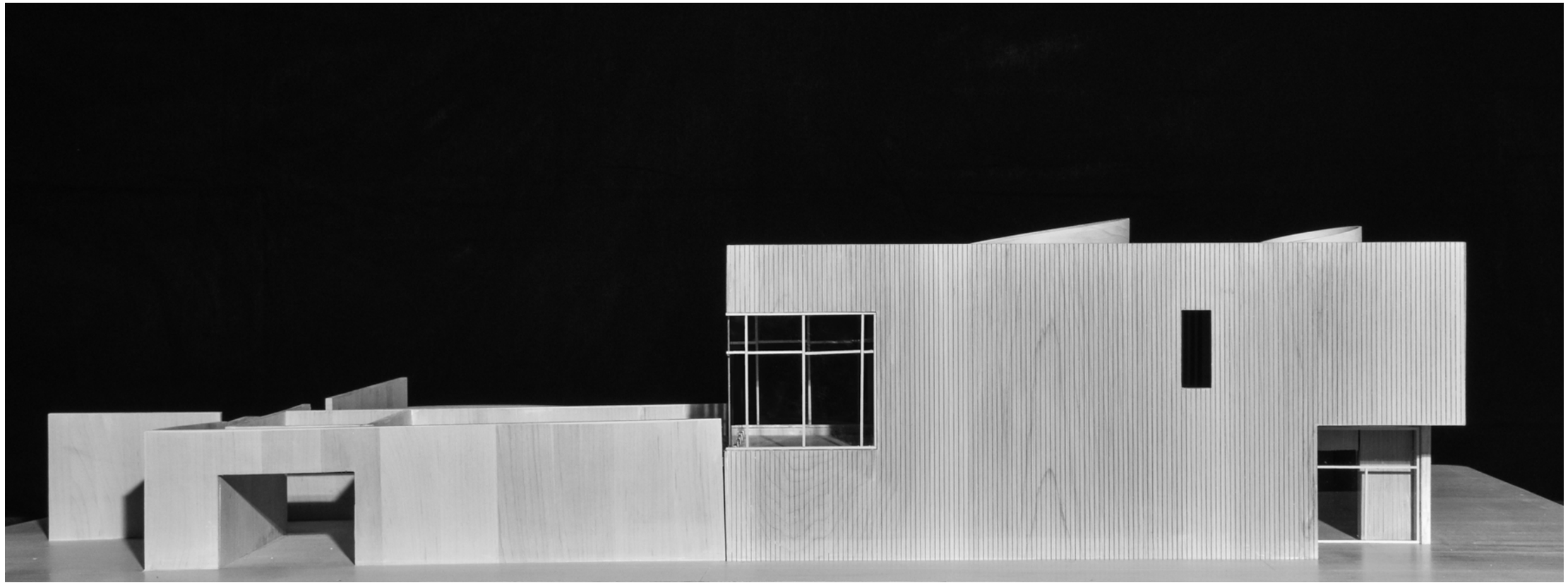




Images that demonstrate how the interior concrete walls and light wells define space through mass and light.



38.

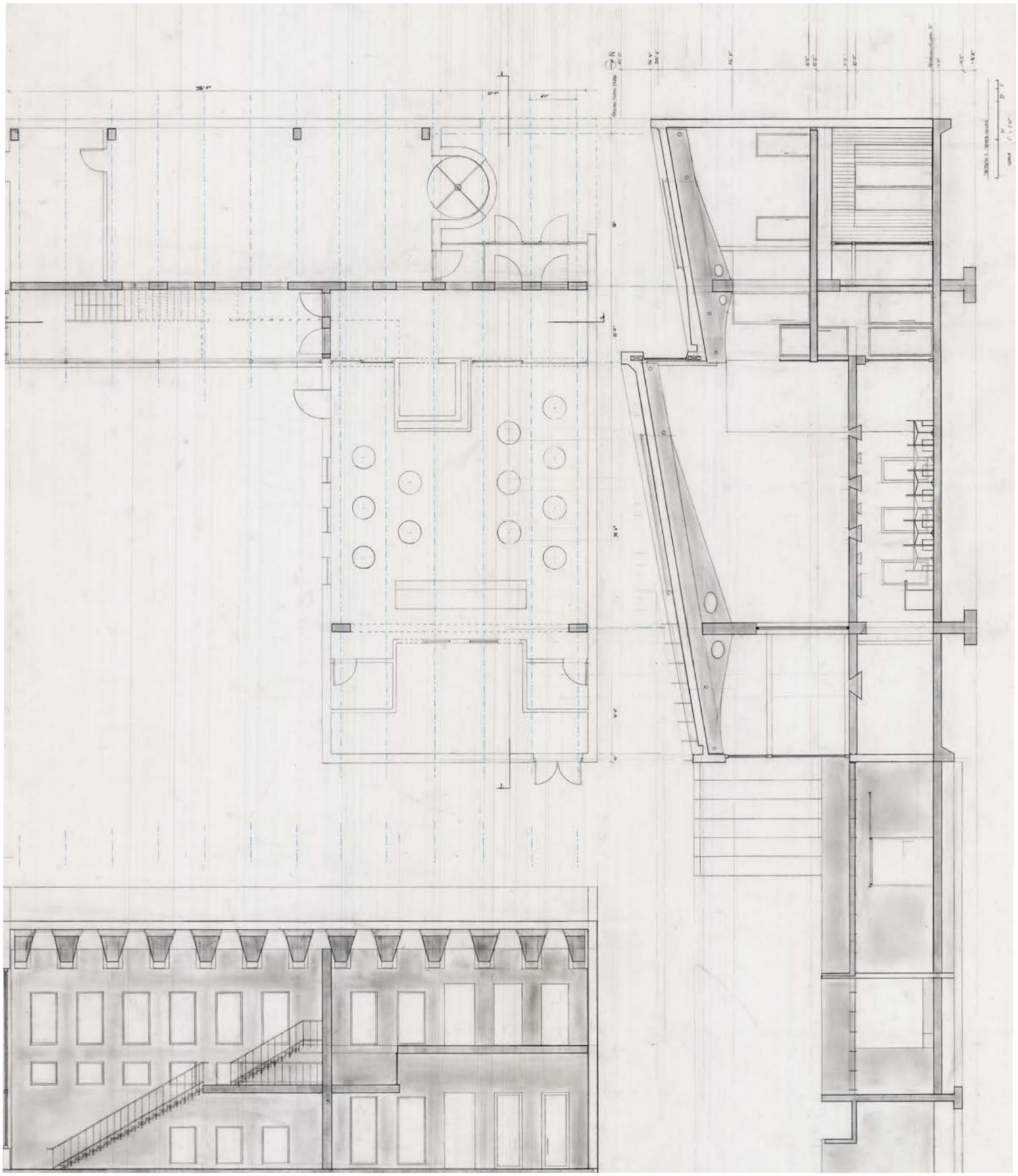
Model photograph of the East elevation

39.

View from the east side showing MLK Ave in the foreground and the Friendship Elementary School in the background.

40.

North/South section study



41.

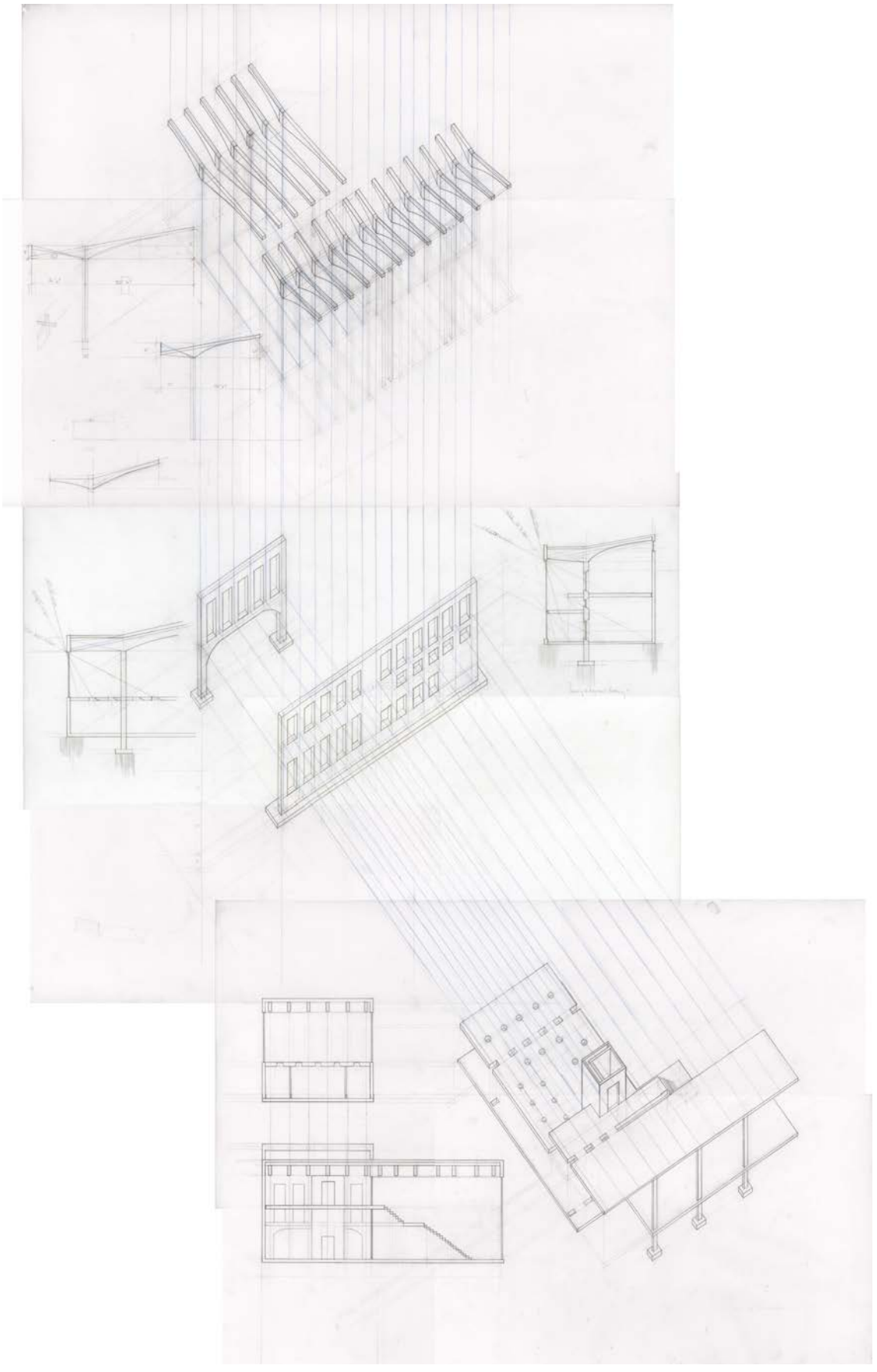
Early version of the ground floor plan with a transverse and longitudinal section

42.

Model photograph of the South elevation

43.

View from the southwest corner looking down the street between Friendship Elementary and the proposed Cornerstore. The tree lined sidewalk to the right leads to the bus stop.

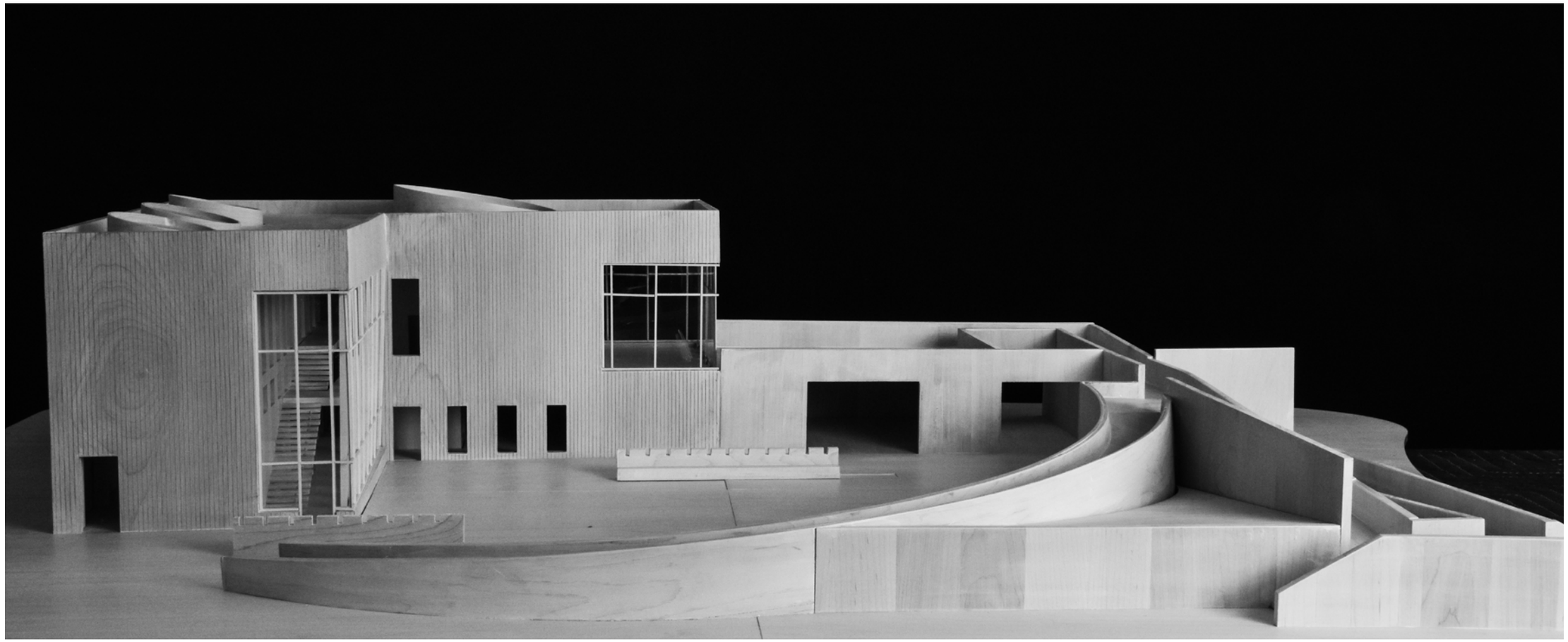


44.

Exploded axonometric drawing of concrete structure with detailed section studies

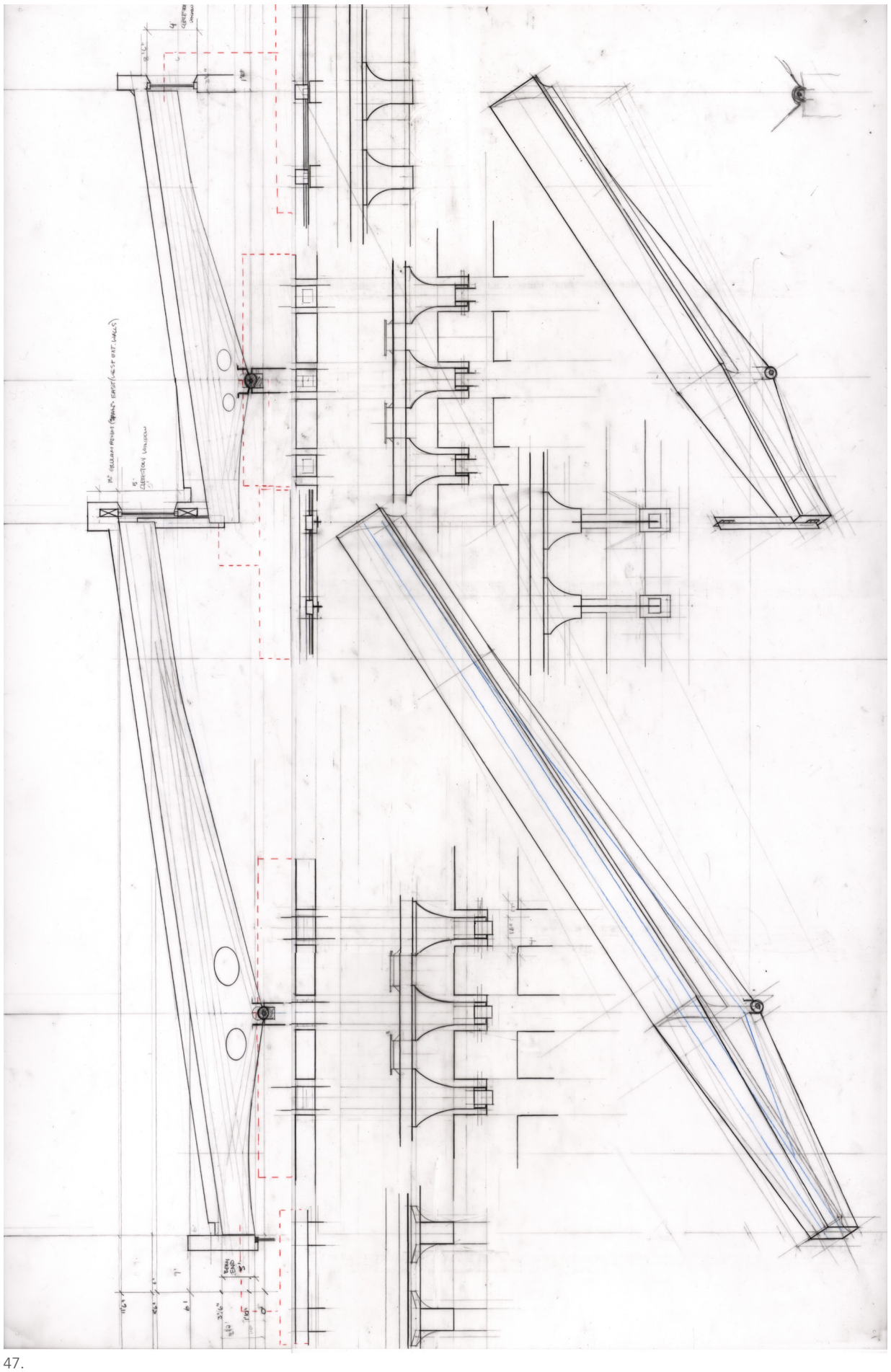
45.

Early axonometric drawing of the Cornerstore site



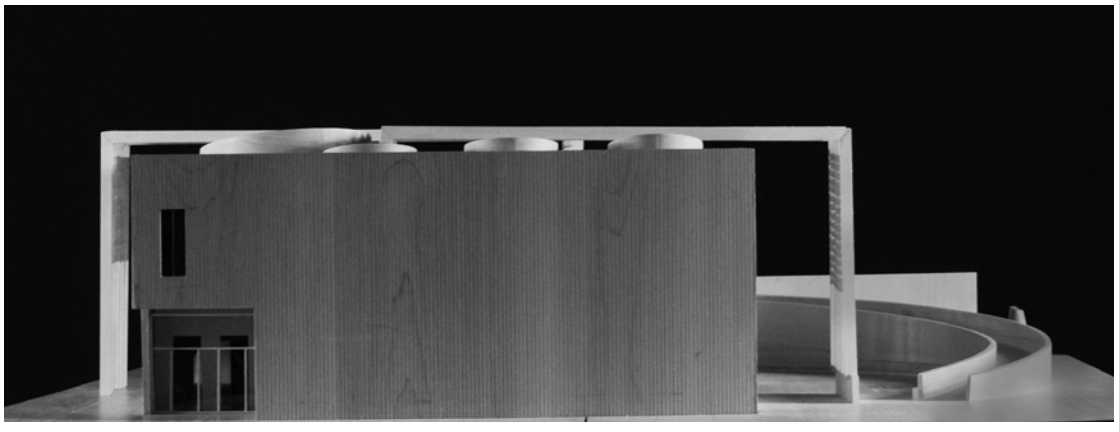
46.

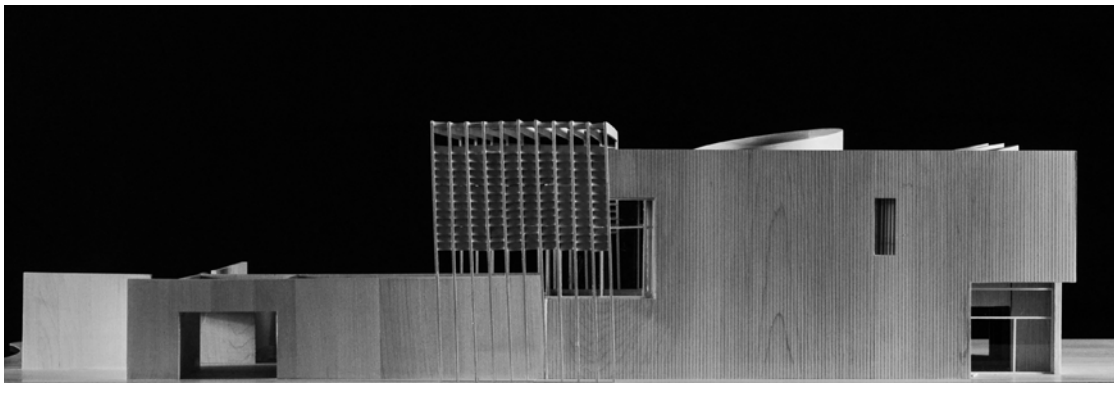
Model photograph of the West elevation

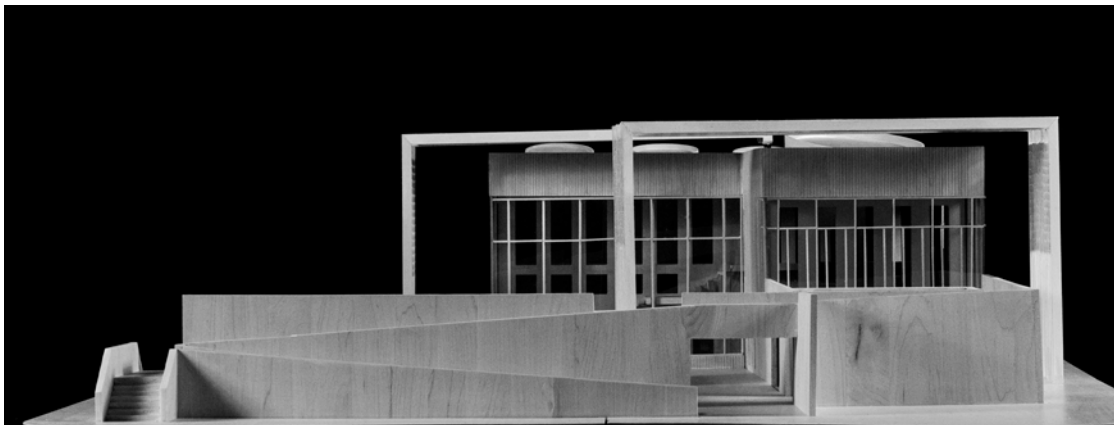


47.

Detail drawing studying a roof system with large concrete trusses

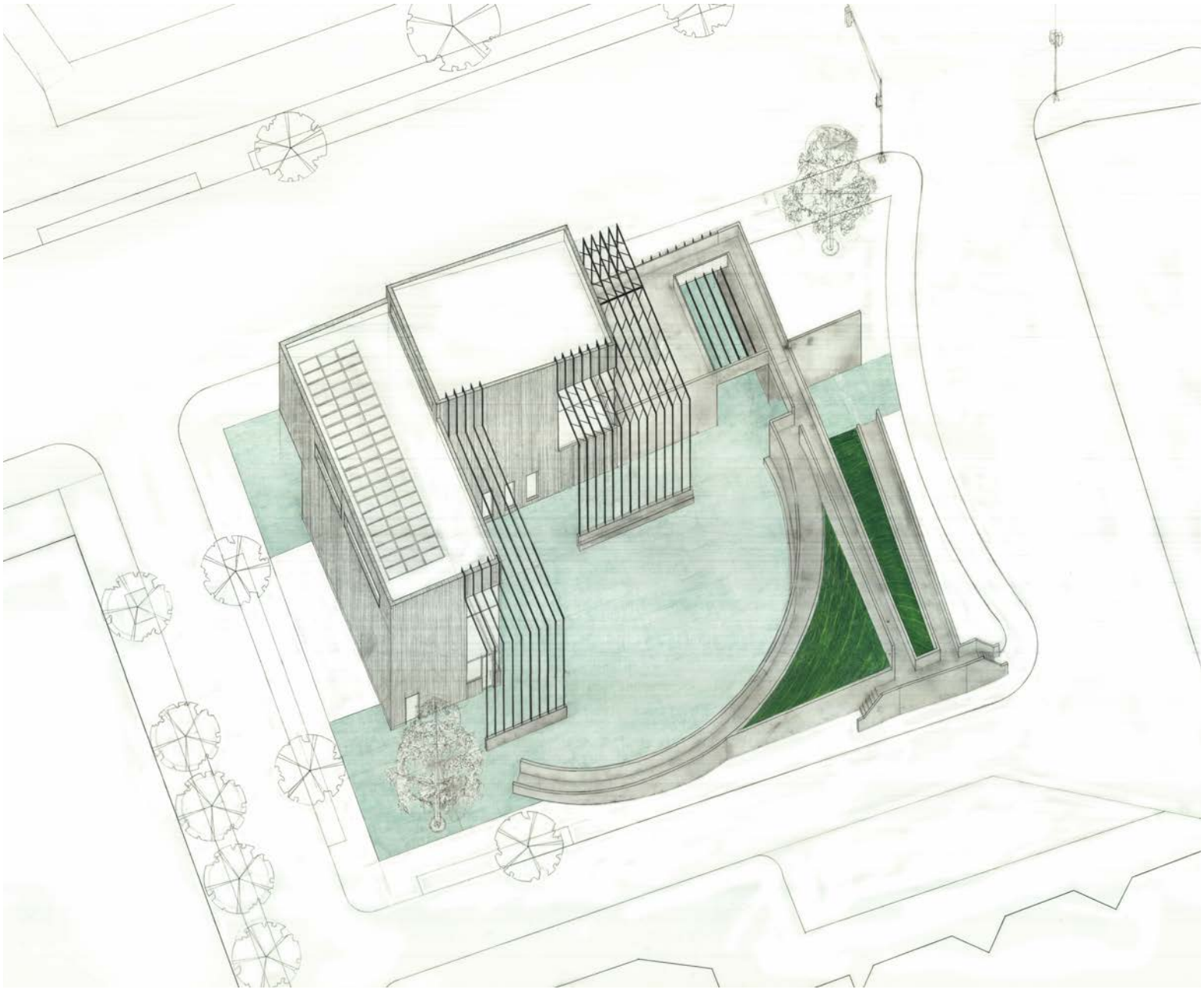
48. 

49. 

50. 

51. 

Elevations with possible shading screens

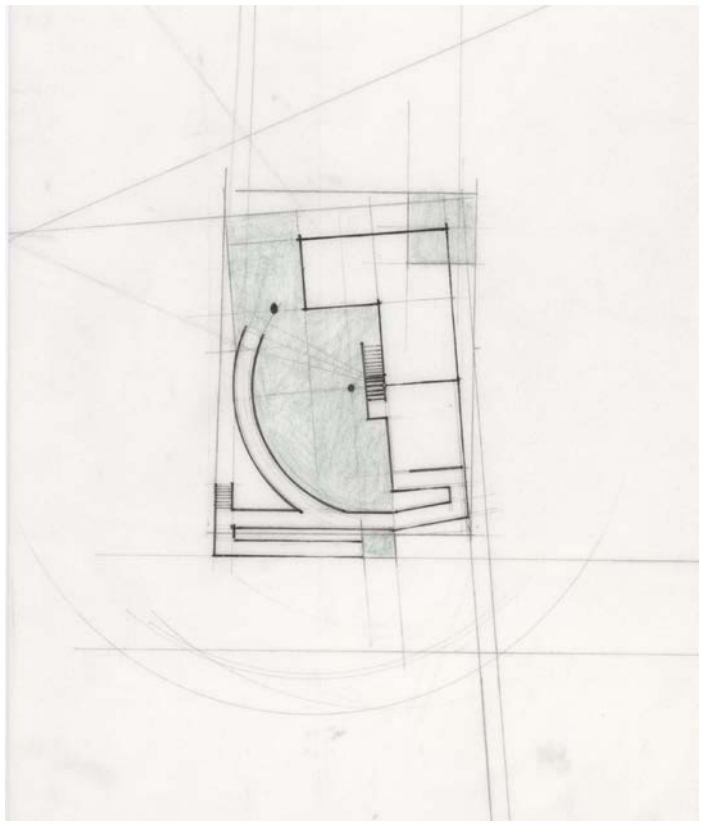


52.

Later version of an axonometric drawing of the Cornerstore site

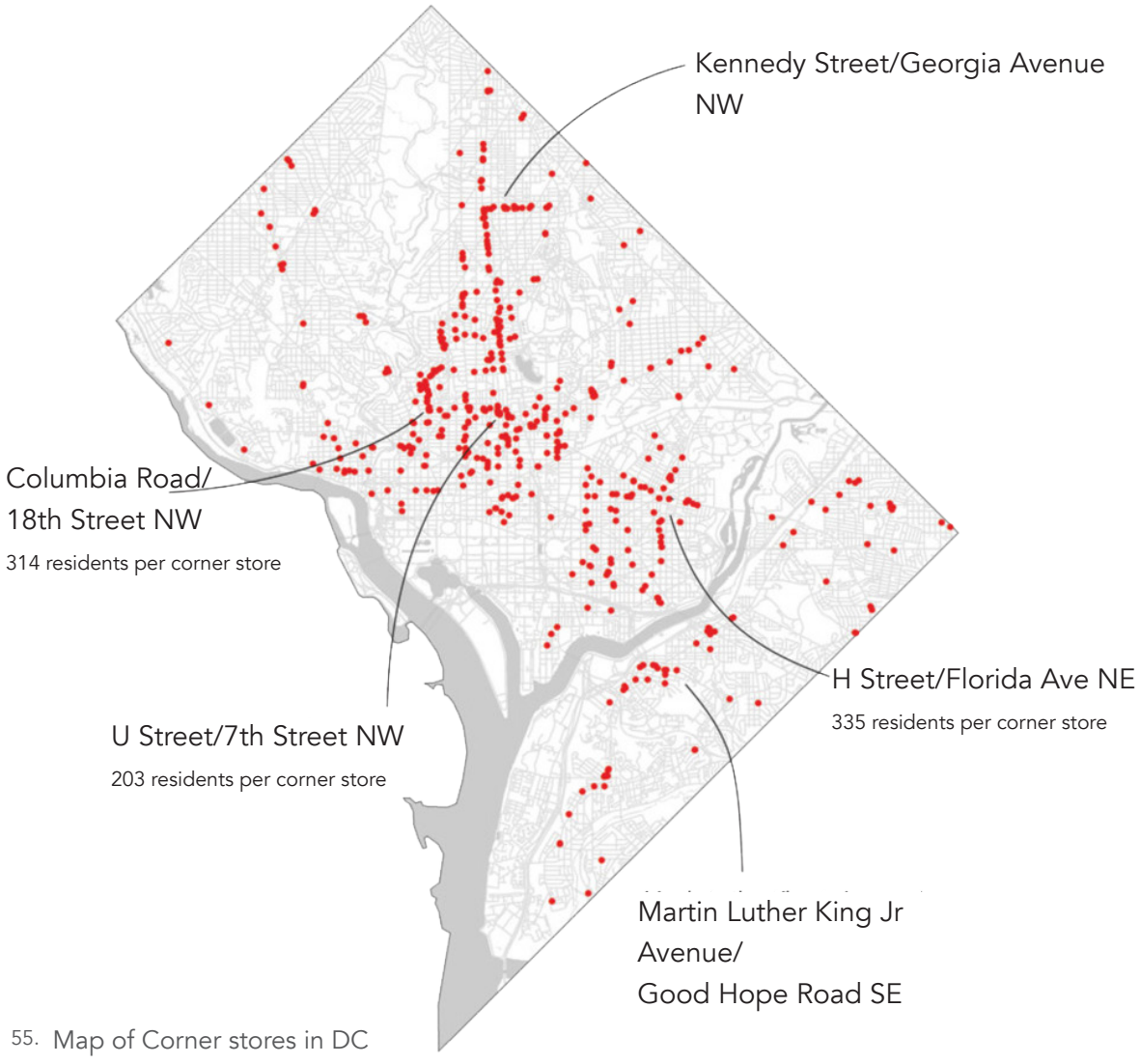
53.

From the south, opening for a pathway to the bus stop



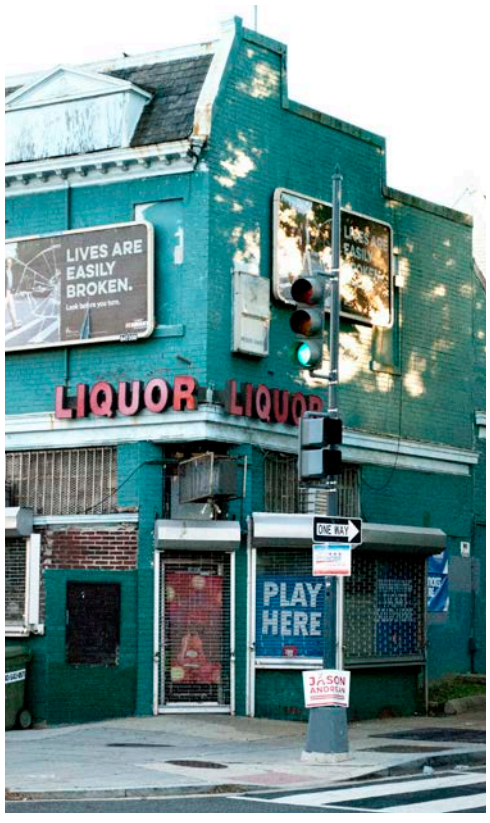
A Place for the Cornerstore

the locus of neighborhood daily life

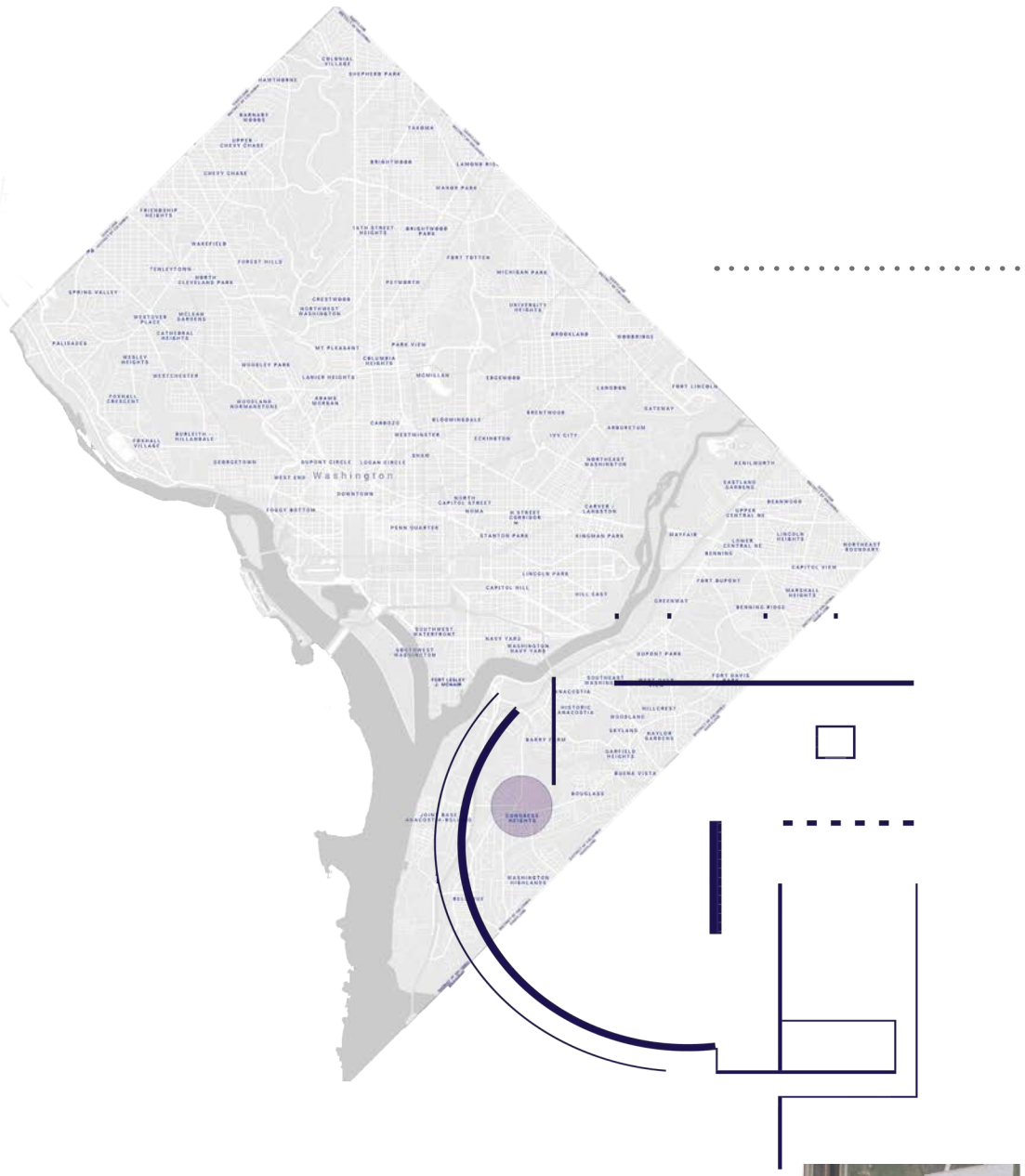


55. Map of Corner stores in DC

Neighborhoods in Washington, DC have corner stores and almost everyone frequents them, no matter what your budget or habits may be. Whether its grabbing a six pack of beer on the way to a friends for dinner, picking up toilet paper or diapers on the way home from work, buying lotto tickets, or kids buying 25 cent candies, we all rely on our cornerstore for the quick purchase. Some have delis or cafes, and in neighborhoods surrounded by food deserts, the corner store can be a primary source of groceries for families. Owners know their customers often on a first name basis, and are willing to stock requested goods and products. The Cornesrtore becomes a locus of daily life, defined by the people of that neighborhood.



56.,57.,58. Three corner stores in Columbia Heights, N.W.

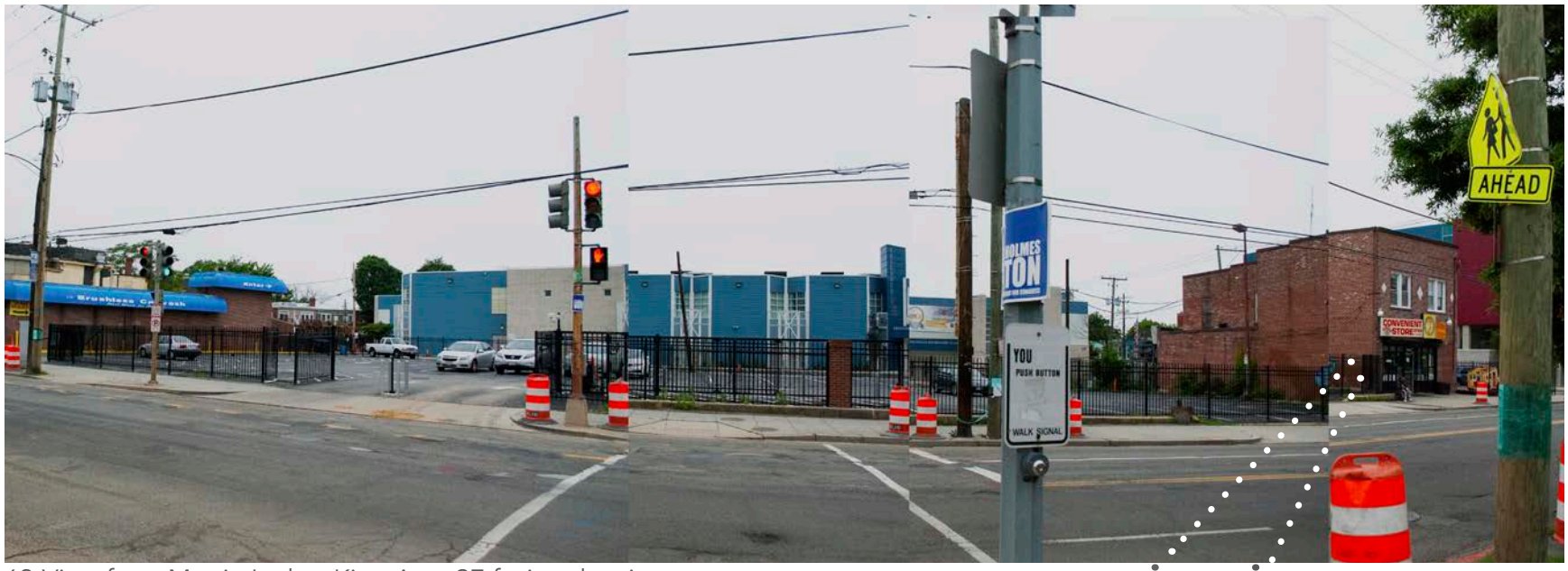


Washington, DC

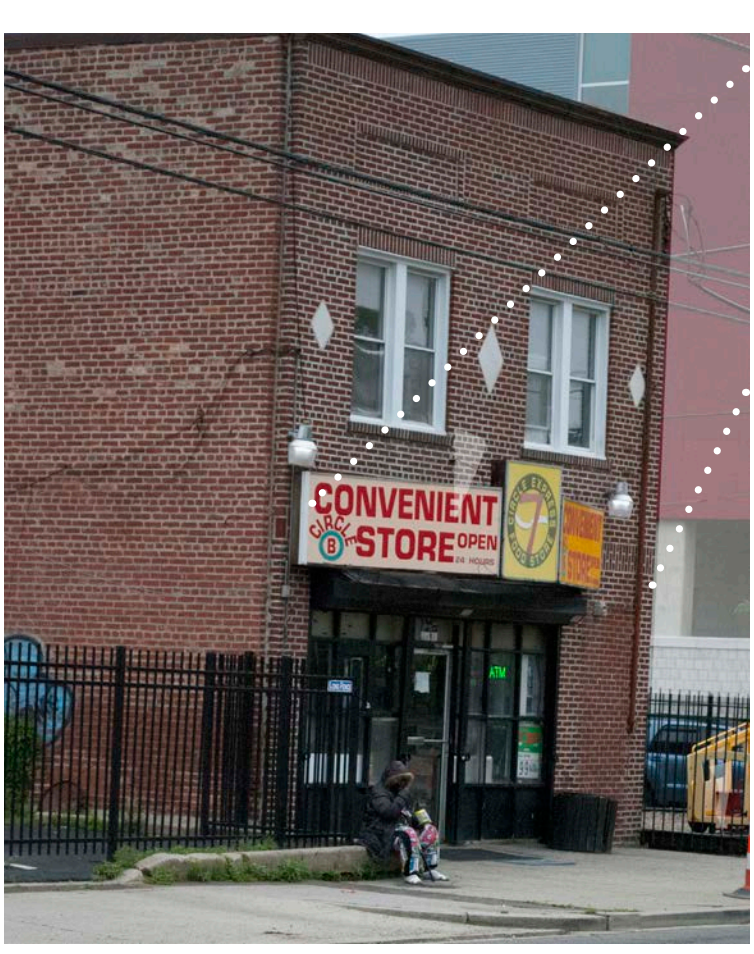
Congress Heights
Ward 8

MLK Ave, SE
and
Milwaukee Pl, SE

59.,60.,61.



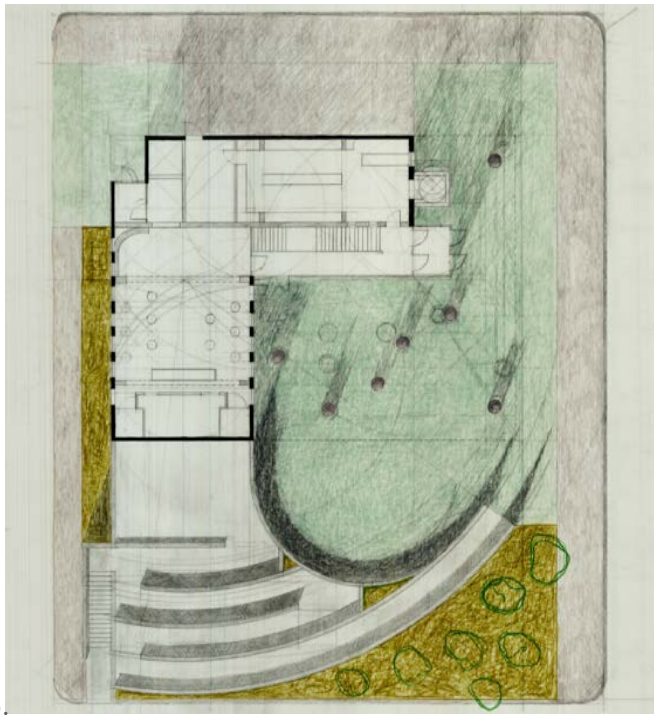
62.View from Martin Luther King Ave, SE facing the site



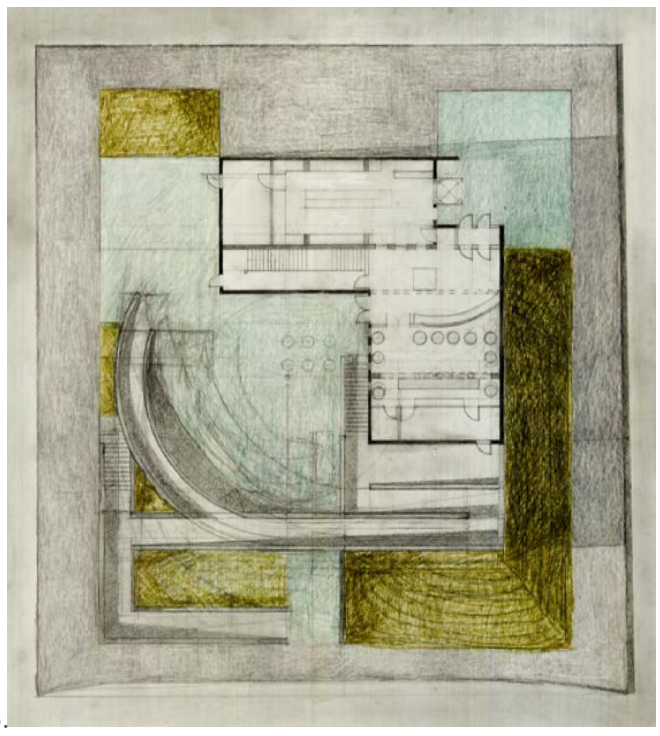
63.The Circle B Convenient Store is currently separated from the rest of the retail on MLK Ave by a large parking lot.

64.

Site and surrounding neighborhood

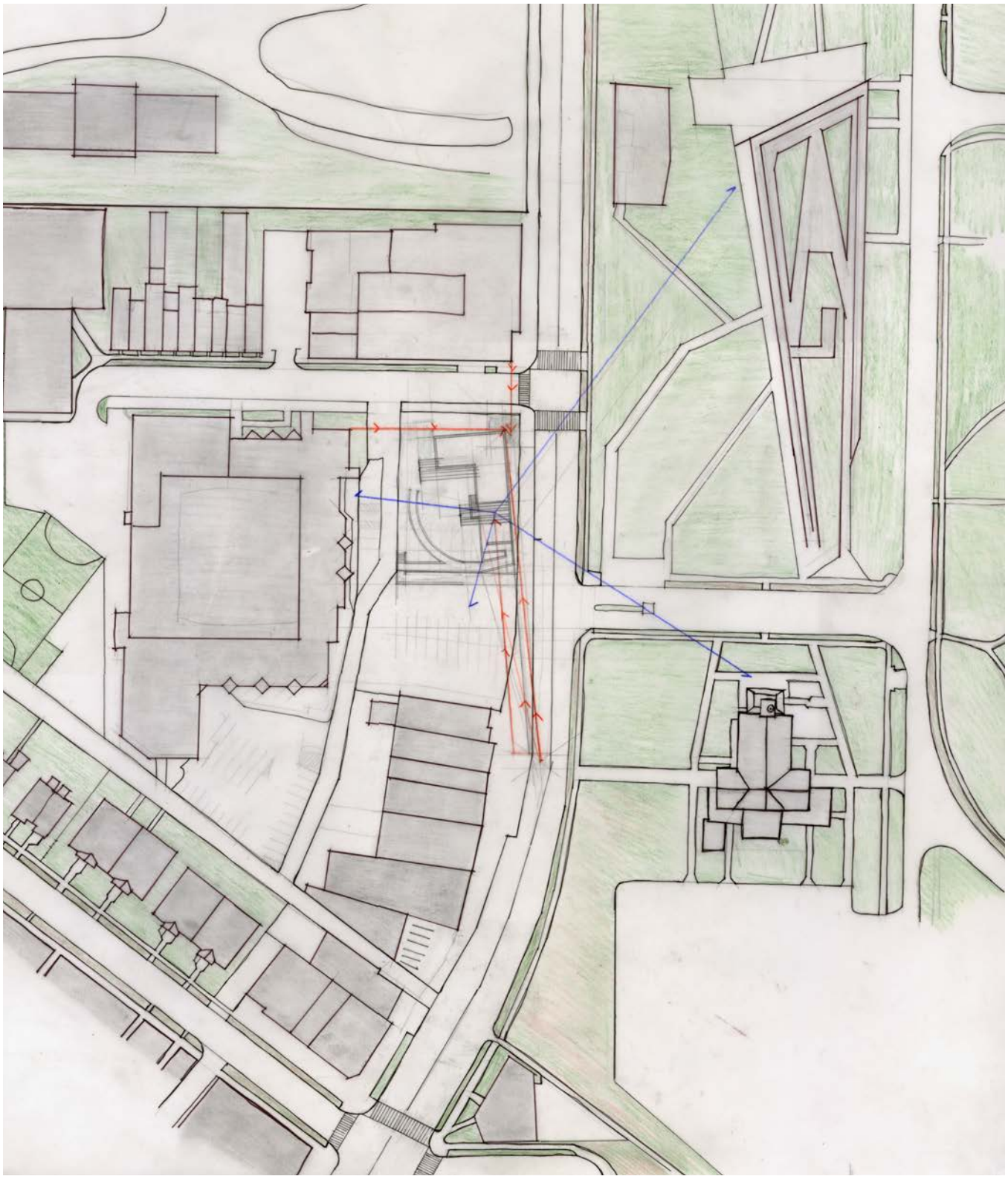


65.



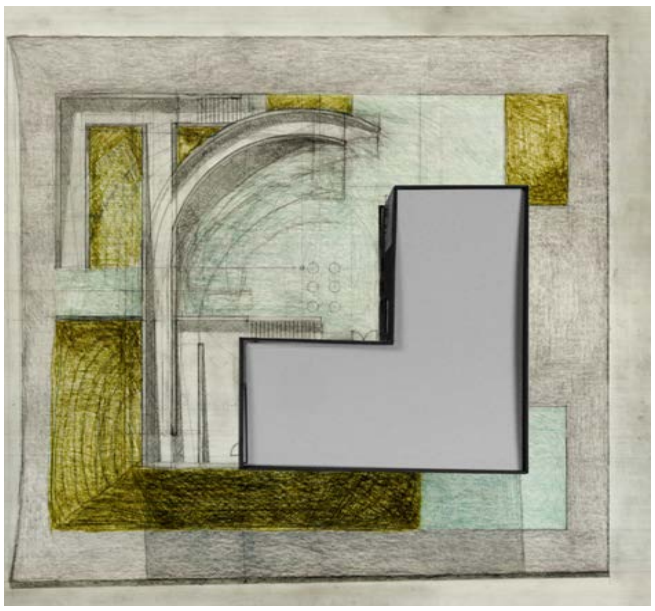
66.

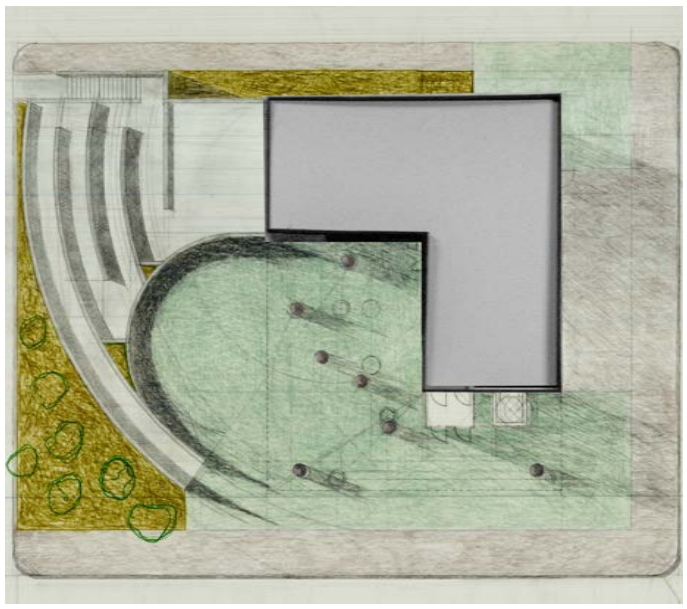
The relationship of the building as an active element of the city is a formal question of the interaction between the site and the street. A building on this location could offer a plaza that opens towards MLK Ave (53.), or an inward focused courtyard protected by walls, ramps, and building mass yet connected to the surrounding streets through pathways and openings (54.).



67. Site study showing points of possible connectivity between the site and surrounding area

68.,69.





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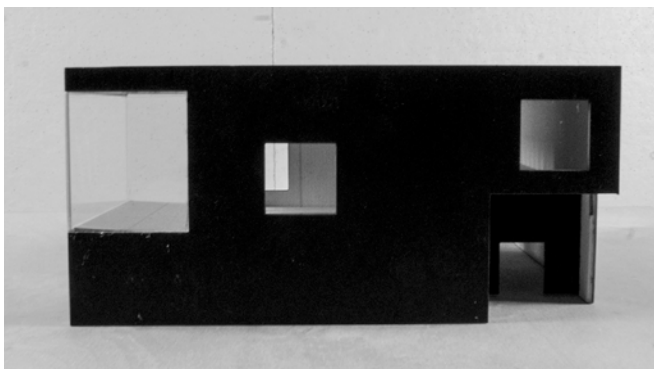

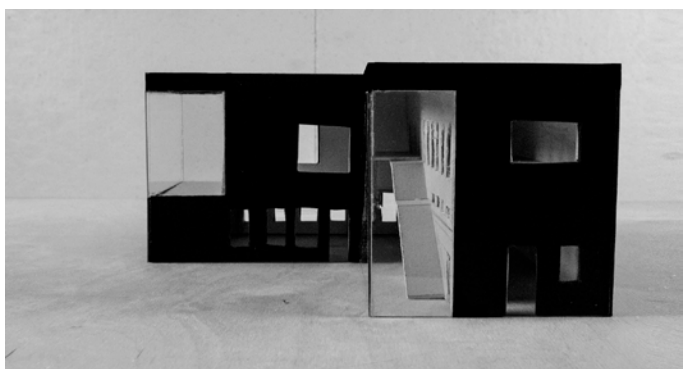

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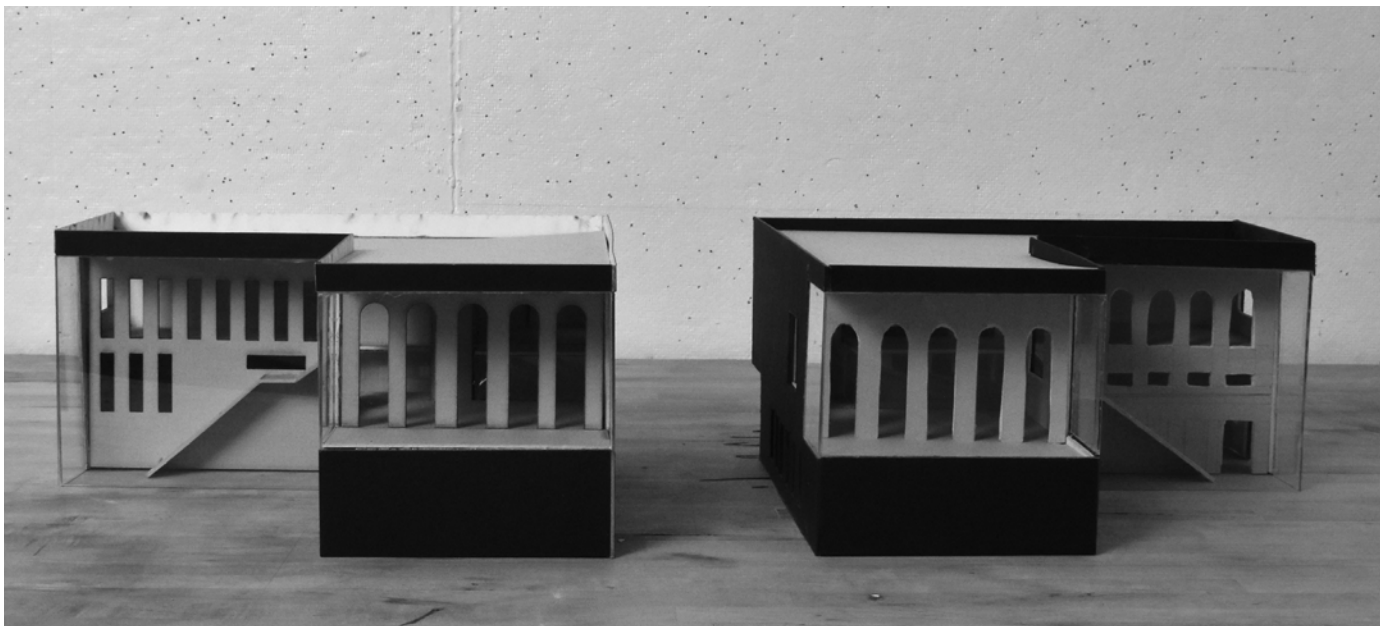
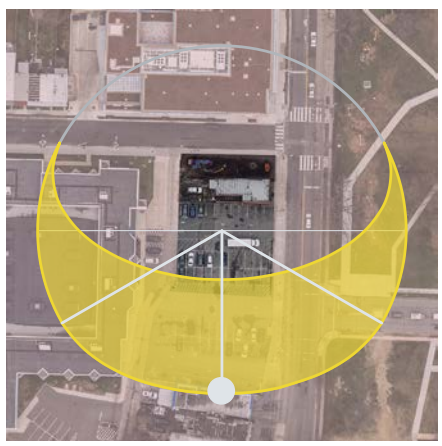


Top: Two site plans with opposite building orientations
Middle: Views of the east elevation of each building orientation as seen from MLK Ave
Bottom: View of the south elevations of each building orientation



Winter Solstice, Dec 21st

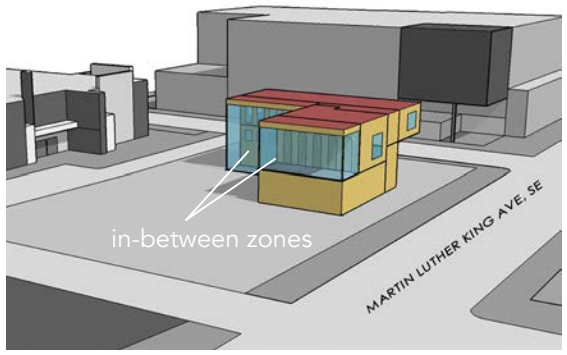
Spring Equinox, Mar 21st

Summer Solstice, Jun 21st

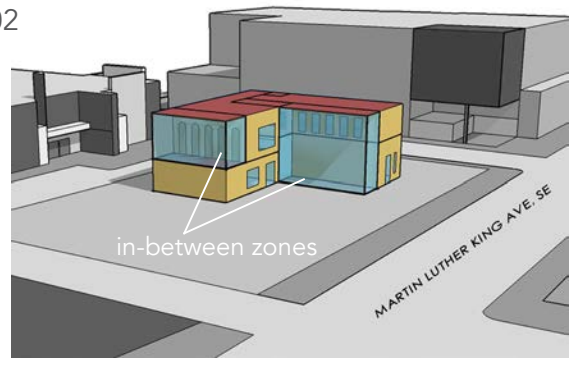
Fall Equinox, Sept 22nd

73. Study of the sun’s path over the site on the four pinnacle days of the year

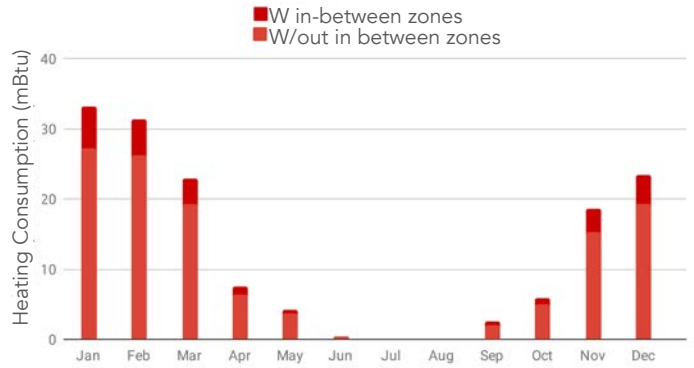
Building

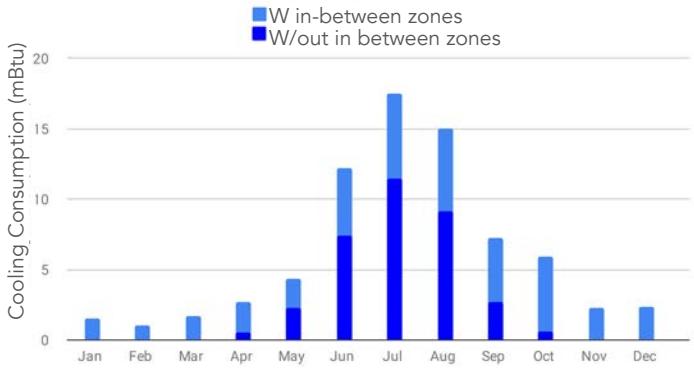


Building 02



74., 75. Models of each building orientation generated in sketchup using the Open Studio plug-in for Energy Plus building simulation.





76. Heating and Cooling Consumption for building 01. The light blue indicates cooling loads with the in-between zones and the dark blue indicates cooling load without the in-between zones. The difference between the two illustrates the excess heat in the in-between zones during the shoulder and winter months. Instead of cooling these zones, this excess heat can be redirected to other zones in the building to offset their heating requirements.

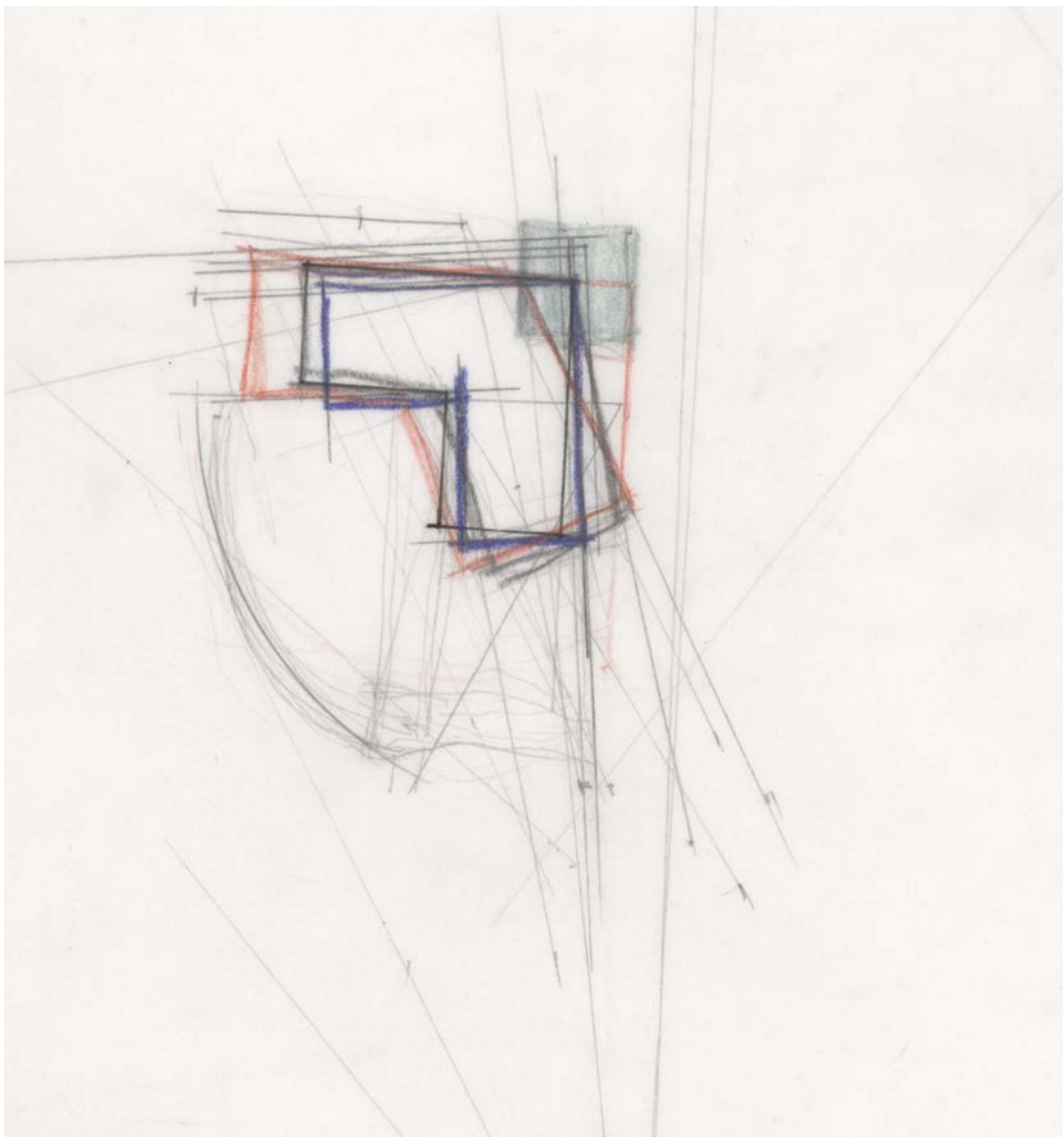
Preliminary energy analysis began with the general parameters of the L shape form, the volume of each programmatic space (organized into eight individual thermal zones), and the two building orientations formally under consideration.

There were three goals of this initial modeling series: 1.to compare the two building orientations (as shown to the left), 2. to compare modeling the in-between spaces (ie, stair/corridor and lower level patio) as interior conditioned zones versus exterior to the thermal envelope in order to understand the impact on the heating and cooling loads, and 3. to evaluate different exterior envelope construction sets for thermal performance.

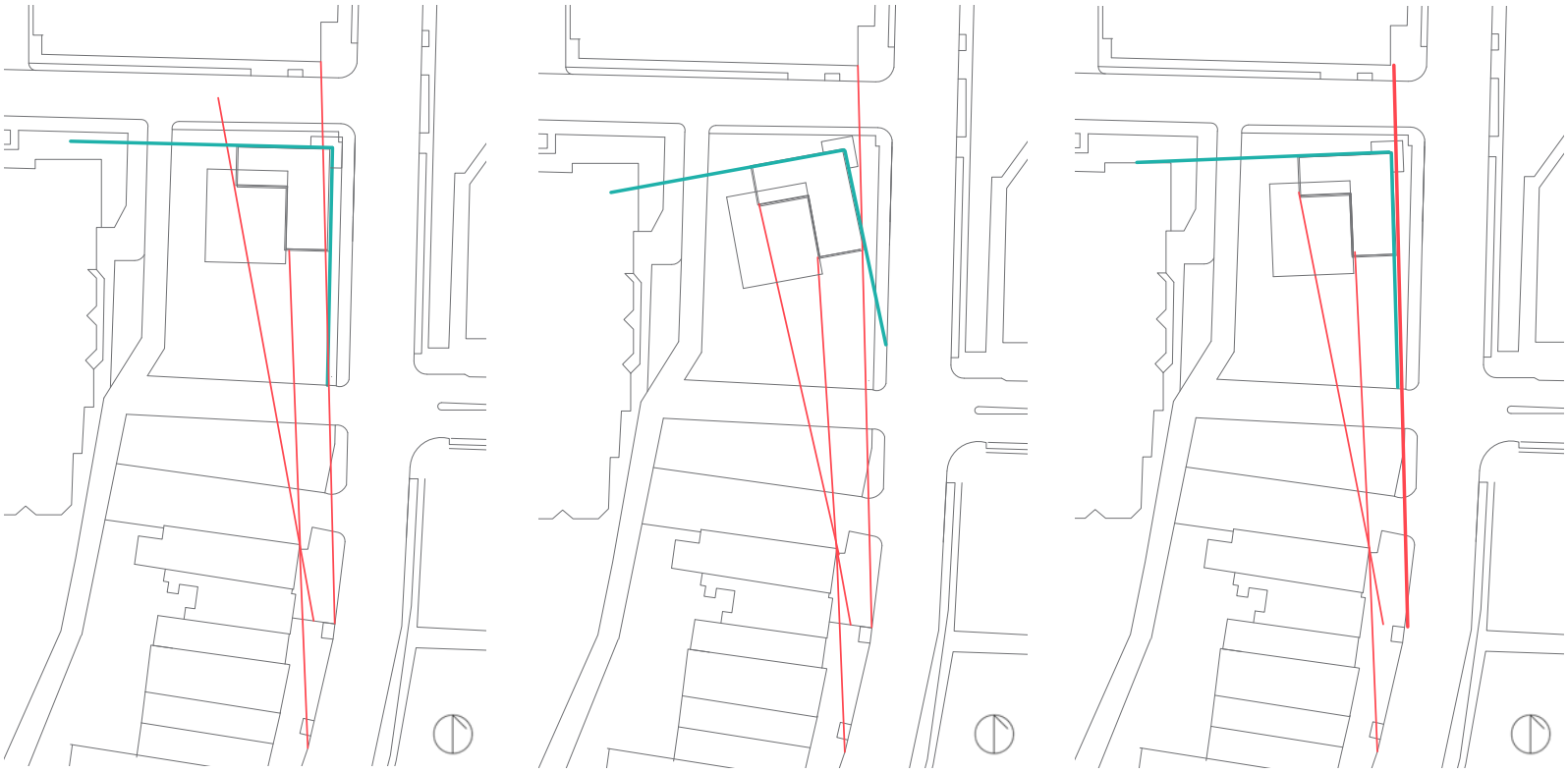
The results found that building 01 had slightly lower total annual heating and cooling loads than building 02, and that the different orientations affect the balance between the heating and cooling loads. Building 01 had higher heating loads than cooling loads and building 02 had higher cooling loads than heating loads. This is due to the relationship between the building orientation and the in-between zones that are mostly glazed enclosures. Building 01 naturally shades the plaza side from morning summer sun exposure but benefits from afternoon and evening sun in the winter. Building 02 gets full morning summer sun exposure and shades the plaza side naturally from afternoon and evening sun throughout the year.

The modeling shows that in-between zones have higher heat gains and losses compared to the rest of the building. Therefore when the building is modeled without these zones included, the overall energy performance improves. This is due to the high window to wall ratio, 70%, in these zones compared to the overall building win/wall ratio of 34%. These zones also increase the annual cooling demand in both building scenarios because they require cooling in the winter months during hours of peak sun exposure.

Conclusions from the preliminary analysis informed the design process moving forward. First, the modeling supported the architectural formal decision to orient the building and plaza away from MLK Ave, as in building 01. Although the modeling showed this orientation performs only slightly better overall, the cooling loads were much lower than building 02. Heating demands could more easily be mitigated than cooling demands through passive measures such as integrating energy recovery ventilation, lowering the exterior infiltration through improved air sealing techniques, redirecting excess heat from the in-between zones to other rooms, and using the thermal mass from the concrete interior walls to store and release excess heat from these zones to adjacent zones. More information on the preliminary energy analysis can be found in Chapter 6, Energy Analysis.



77.

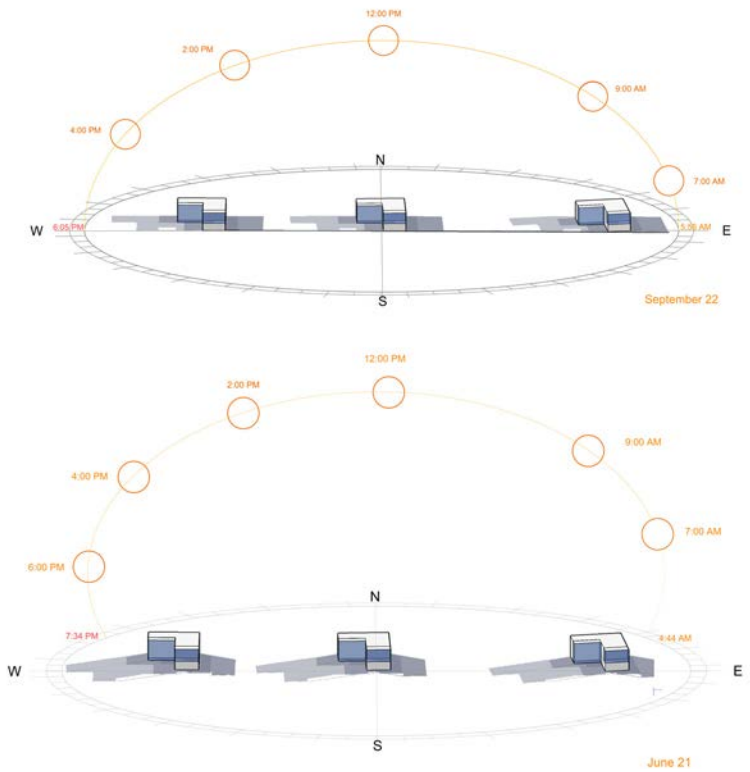


78.

Parallel to MLK Ave

10° rotation from MLK Ave

03° rotation from MLK Ave

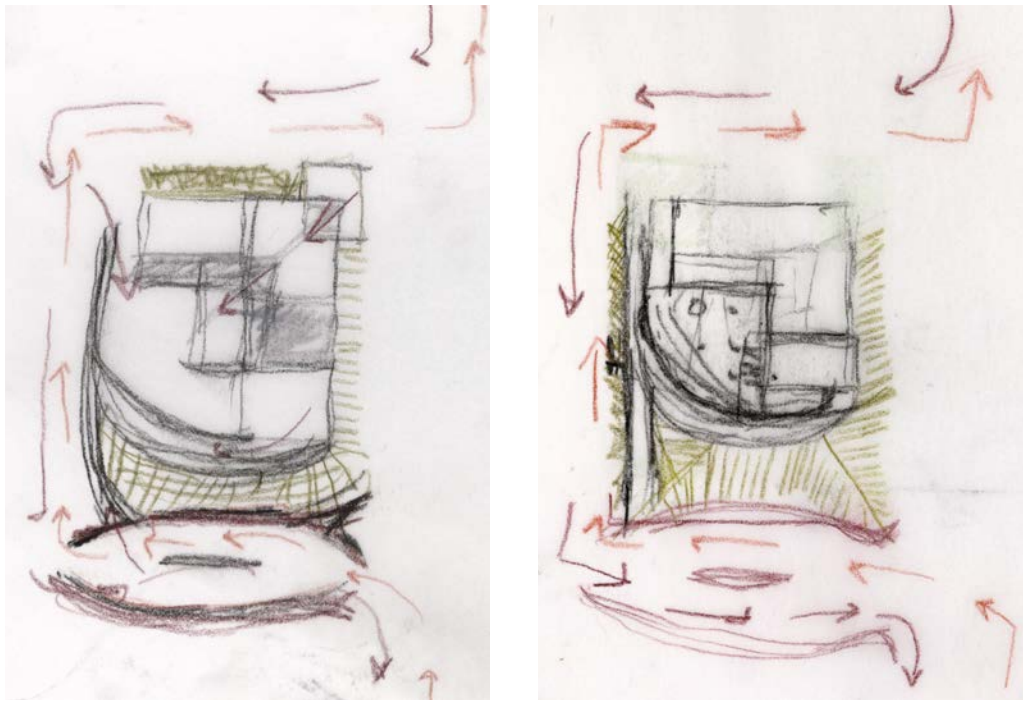


79. The building and its shadows at each angle of rotation over the course of the day on the Fall Equinox and Summer Solstice.

The rotation of the building away from parallel with MLK Ave is a formal question of site connectivity and an energy question of sun exposure.

Regarding sun exposure, the act of rotation moves the building away from a directly north/south orientation. To rotate towards the south east improves the building's ability to naturally shade itself from the late evening sun in the summer and maximizes exposure to evening winter sun. The energy simulations of the final building rotated 03° show a 7.5% improvement in the heating and cooling loads, a significant amount when trying to meet the standards of low energy building requirements.

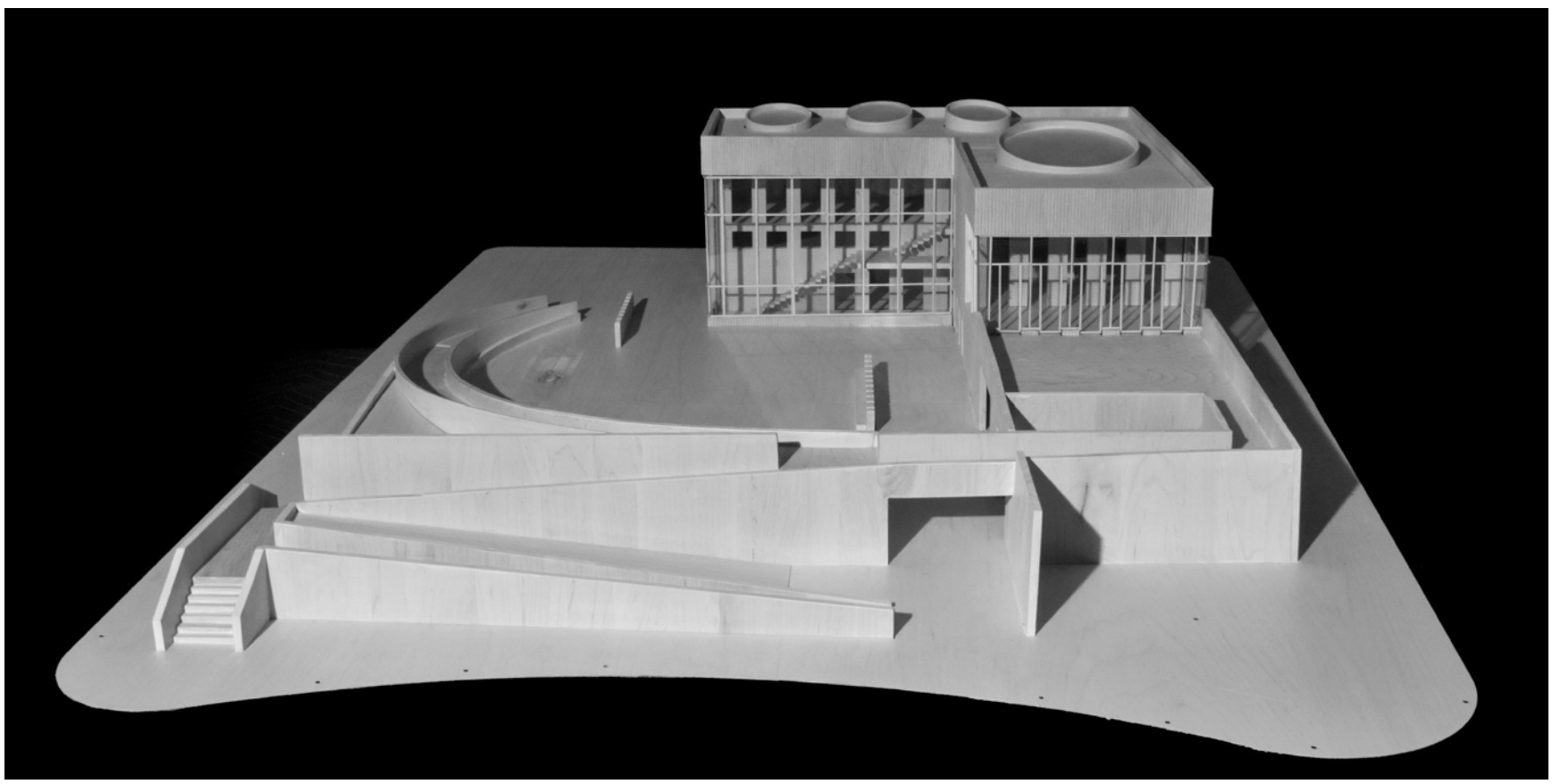
Formally, to rotate the building allows a visual connection to the two schools at the corner of Milwaukee and MLK Ave, in two directions. The building rotated at 03° faces towards the bend in the road south on MLK Ave allowing a line of site to the Friendship Public Charter Highschool located on the north side of the intersection. At the same intersection but looking down Milwaukee Pl, the rotated building also gives a better line of site to the Friendship Public Charter Elementary School, located to the east. Thus, the act of rotation gives the two schools a stronger presence on the corner.



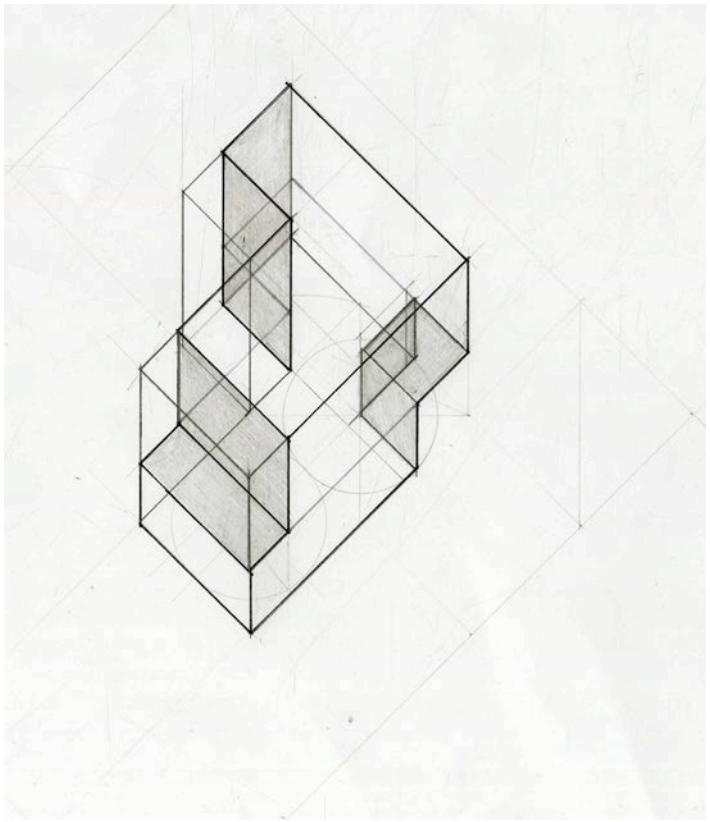
80. Study sketches of how the site might engage with the new bus stop.

81.

The most recent building proposal in the urban context including the new proposed bus route.



82.



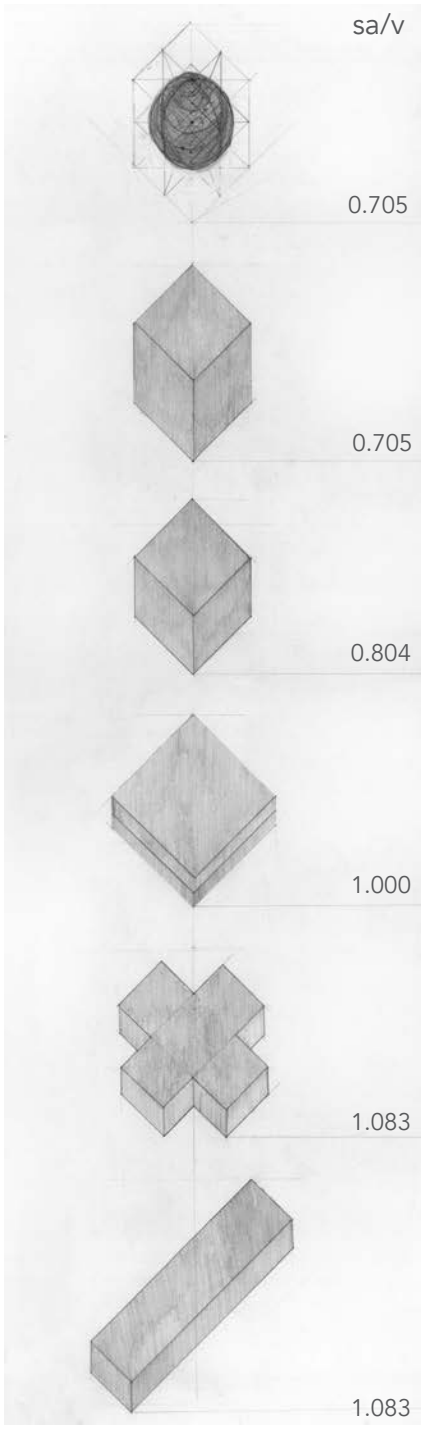
Negation

"A negation is not simply a cancellation of an affirmation. Rather it suggests a certain complexity that simultaneously incorporates an affirmation and the qualification of that affirmation. Bergson states that negation differs from affirmation "in that it is an affirmation which itself affirms something of an object." The inherent complexity of a term that both affirms and qualifies an object opens a space in a discourse that would otherwise close down upon itself. The nothingness that positivism attempts to supplant by its rational activity is not devoid of meaning, but is rather an expectant field of possibilities. Again, Bergson finds a complexity in the "one dimensional" term when he describes nothingness of the void as "the idea, distinct or confused, of a substitution, and the feeling, experienced or ingrained, of a desire or regret." It is the possibility that nothingness can admit to. As a process towards nothingness, negation creates a space of absence, which the expectant grain of our emotion may arise."

Dan Hoffman on Henri Bergson as written
in the essay "Un-Making and the Possibility
of Critical Work."

84.

Through subtraction, new space is created.
Negation defines the in-between.



85.

The compactness of an object can be measured by the ratio of surface area to volume of the enclosed object.

It demonstrates how an enclosure responds to its surrounding environment.

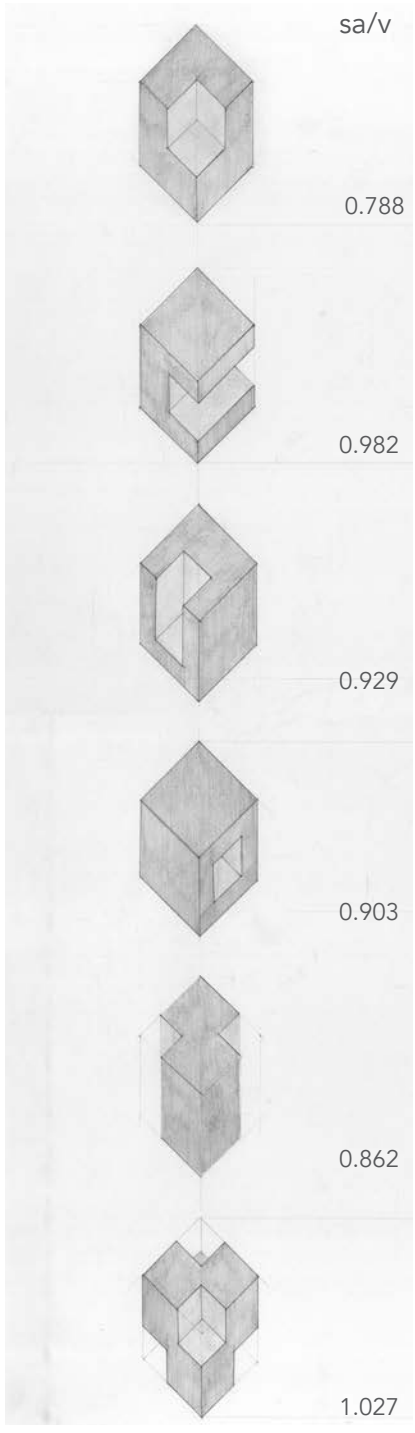
The enclosure defines the boundary between the interior conditioned space of a building and the exterior. As it interacts with the exterior conditions, thermal energy transmission occurs.

Smaller surface areas of an enclosure allow less thermal energy to transfer from the interior volume to the exterior environment and vice versa.

A sphere is an ideal form for a given volume in terms of compactness because it lacks corners or transitions from one surface plane to another where most often energy loss can be the greatest.

A sphere is the same in compactness to a cube, when the diameter (d) of the sphere is equal to the length of a cube (x); d=x. In this series, where x= 8.5, the sphere and cube have a surface area to volume ratio of 0.705.

This series shows different volumetric configurations that have a surface area to volume ratio less than or close to 1.0.



In this series, the forms maintain a surface area to volume ratio of less than 1.0 and are generated using a subtractive process.

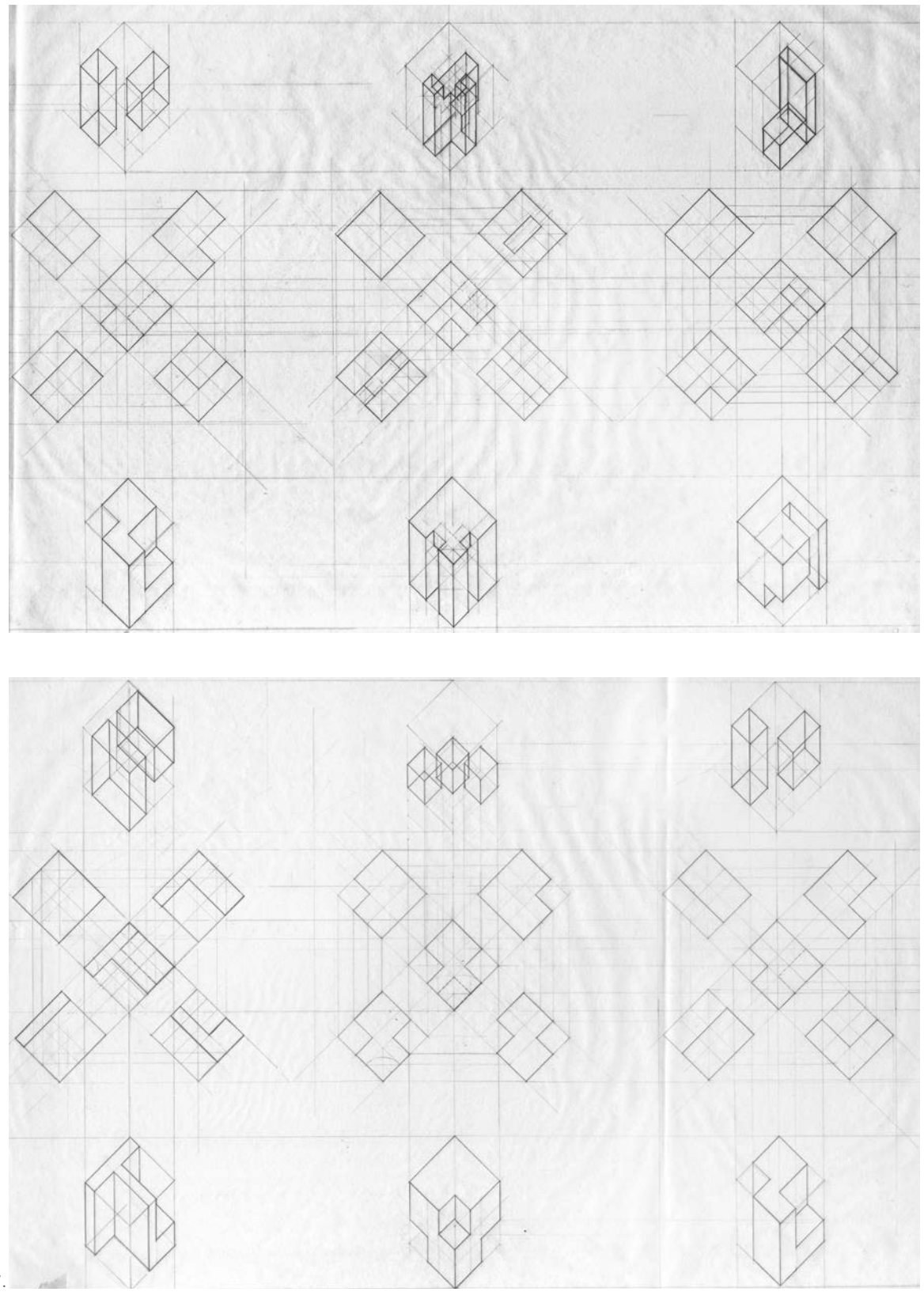
Starting with a baseline cube, 8.5 x 8.5 x 8.5 in dimension with a volume of 614.125, smaller cubic volumes are removed in various ways from the baseline. Each time a cube is removed, the total volume of the form is reduced. The surface area, however, doesn't always change.

In the first form of the series to the left, a cube is removed from the corner. The volume is reduced the but the surface area does not change. Each plane that is affected by the subtraction maintains the same area as before the subtraction. This is also true in the last form of the drawing.

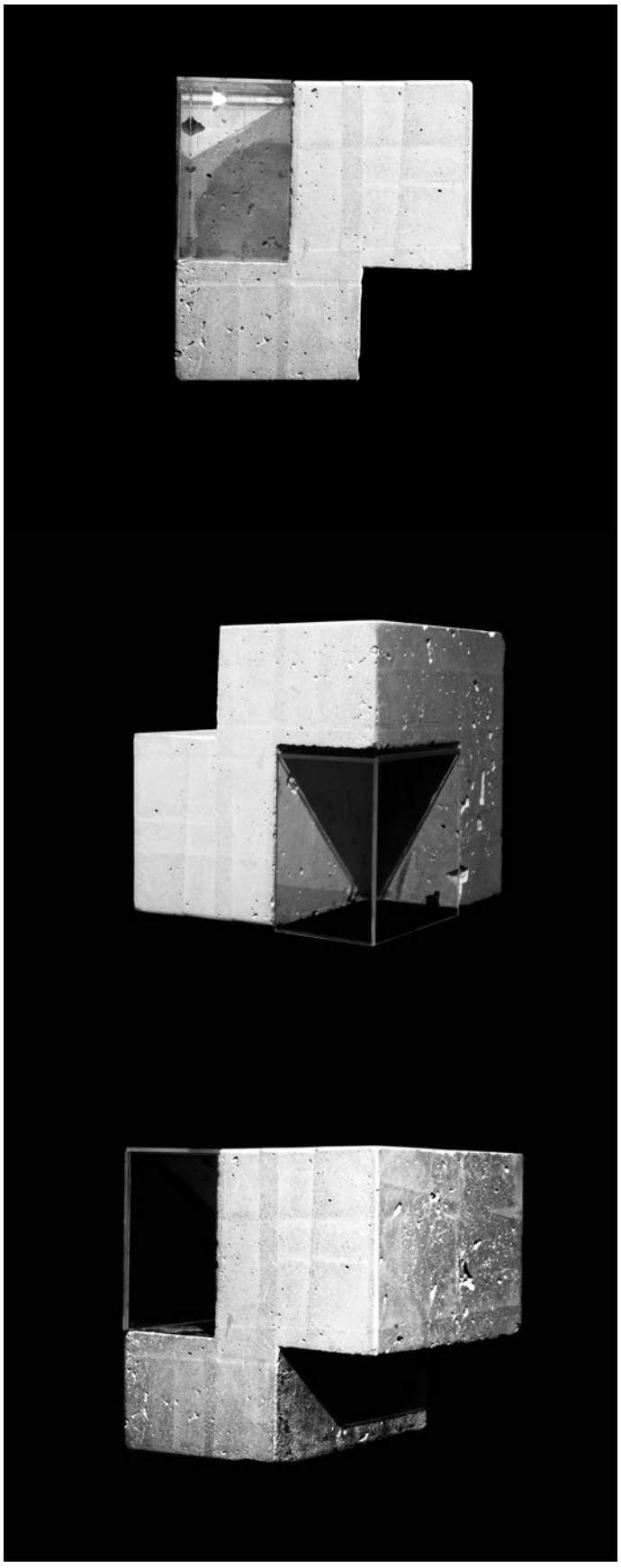
When volume is subtracted from one or more surfaces of the cube, but not at the corner, the surface area will increase. If the mass is removed from one surface only, as in the fourth form of the series, the surface area increases by four planes of the subtracted volume. If the volume is removed from two surfaces, as in the second and third forms, the surface area is increased by three planes of the subtracted mass.

In the fifth form of the series, the volume is removed from the entire corner, affecting four surfaces. The volume and the surface area are both reduced.

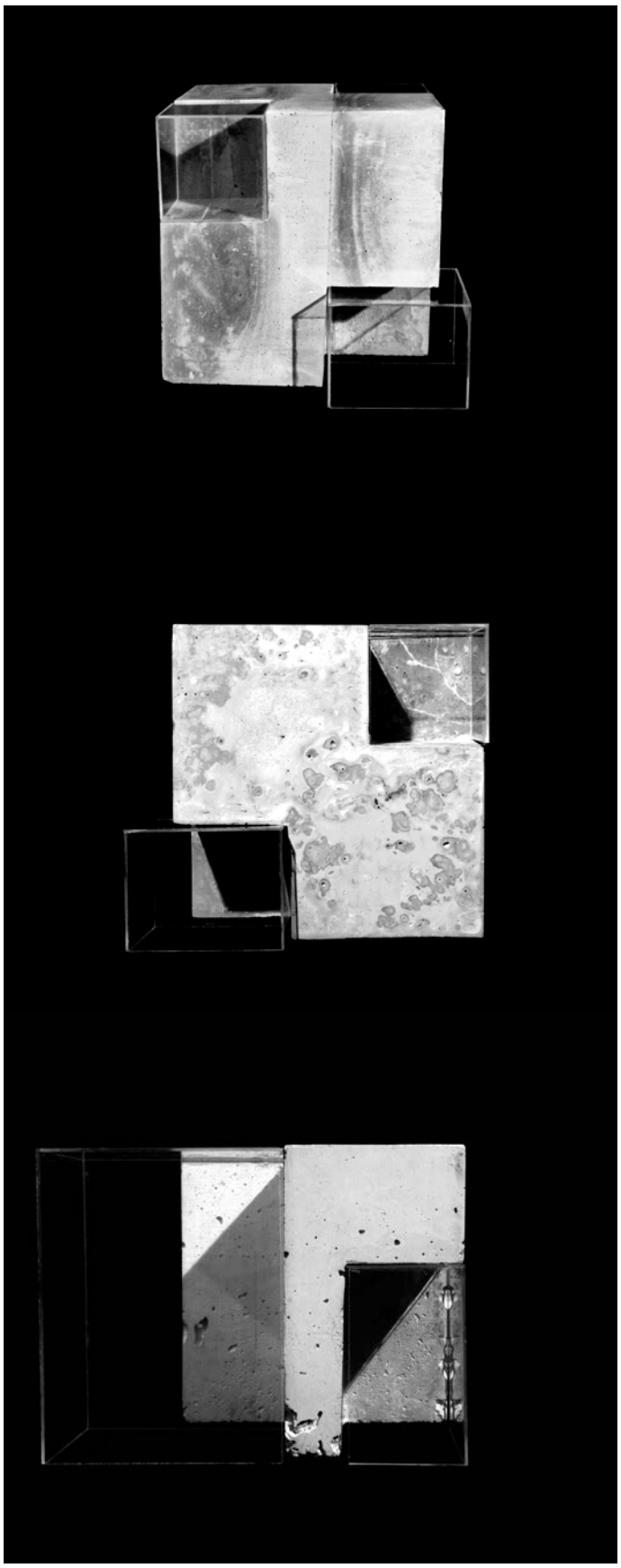
86.



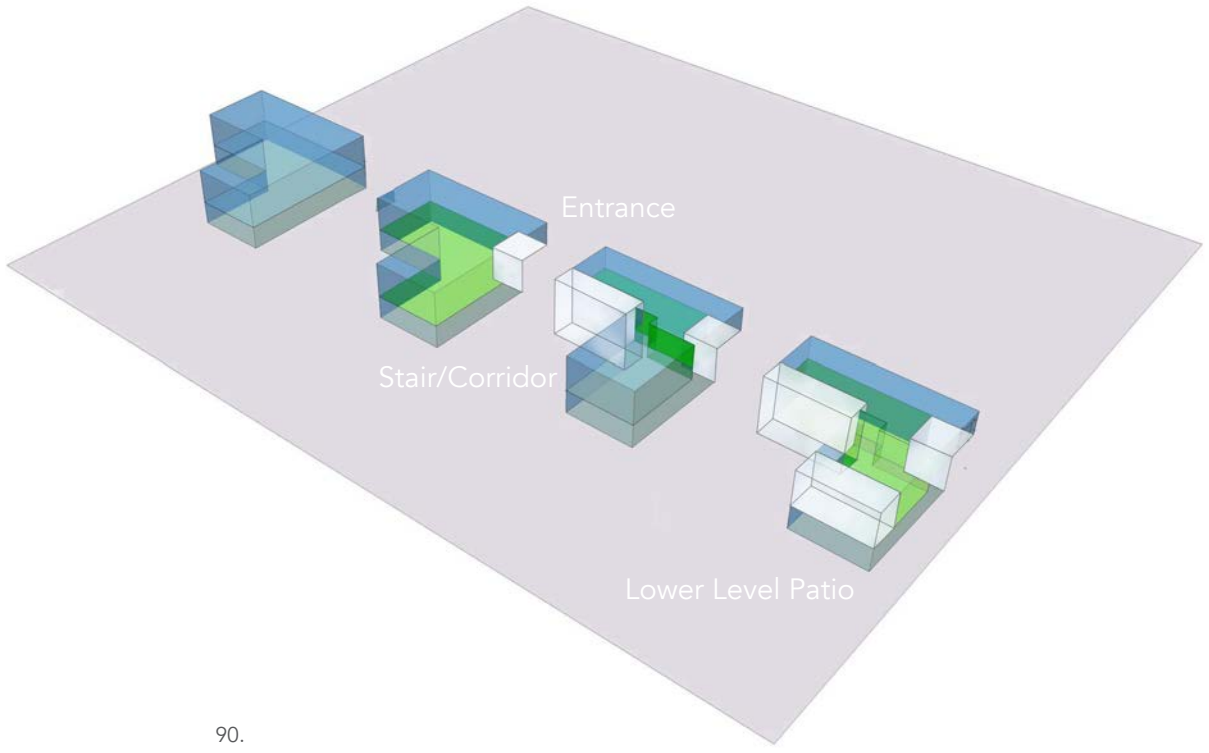
87.



88.

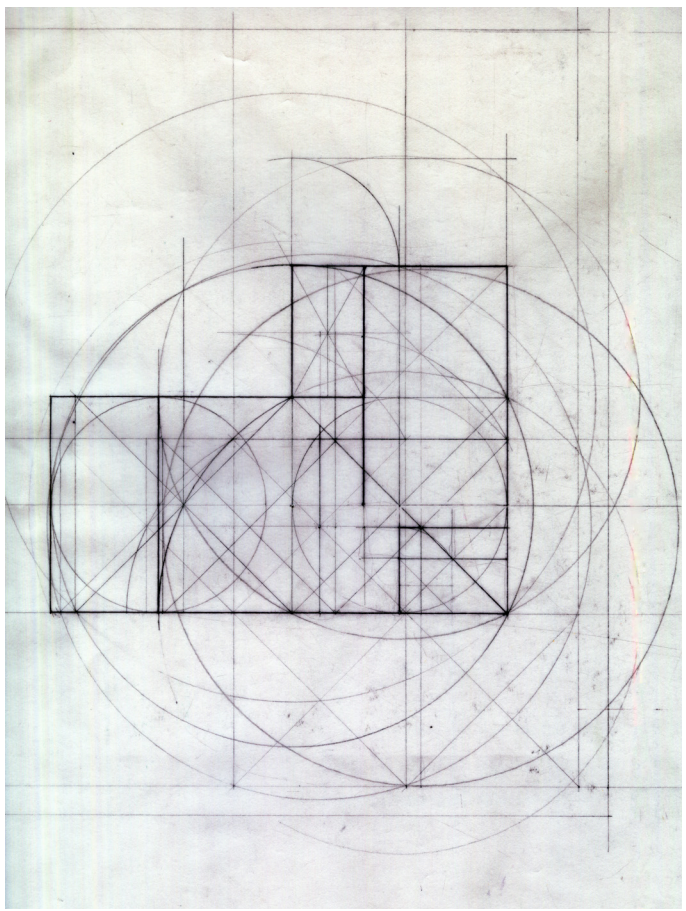


89.



90.

Through the subtractive process the entrance, stair/corridor, and lower level patio become new spaces in-between, using the principles developed in the study of negation.

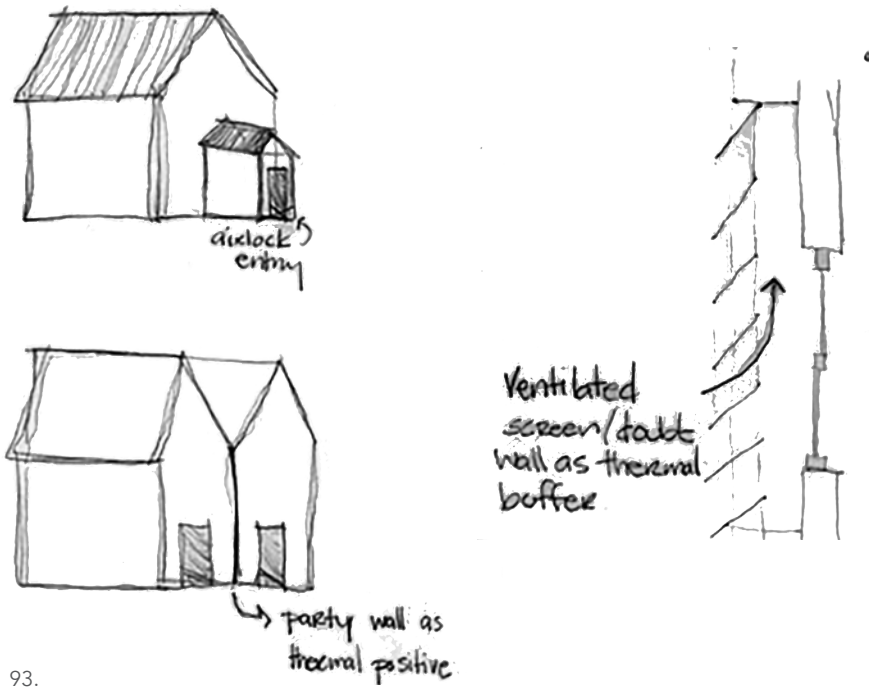


Occupy the Boundary

the space between

Boundaries engender causation. In the engagement of or defiance towards the boundary, architecture articulates space. Boundaries can be physical or phenomenal delineations of space and both concomitantly. It is where the beginning and end meet in a moment of transition, repetition, or possibly a dynamic state of motionlessness. Therefore, in boundaries exists the potential of form.

92.



93.

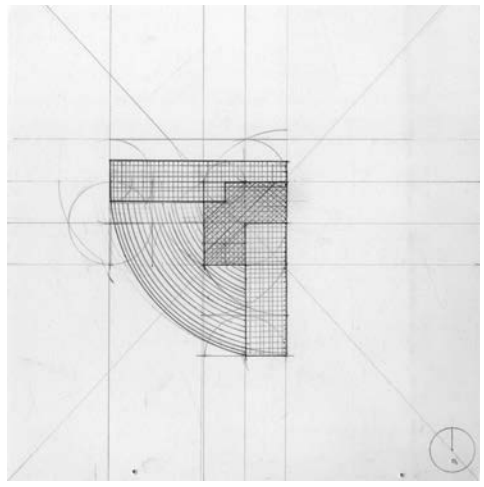
In energy efficient design, the envelope is defined by the layers that separate the interior conditioned space from the exterior surrounding environment. The air, thermal, moisture, and vapor control layers are the key components of the envelope that together establish this physical boundary. To occupy the boundary is a question of how this physical moment of transition between interior and exterior can expand to become a phenomenal occupied space.

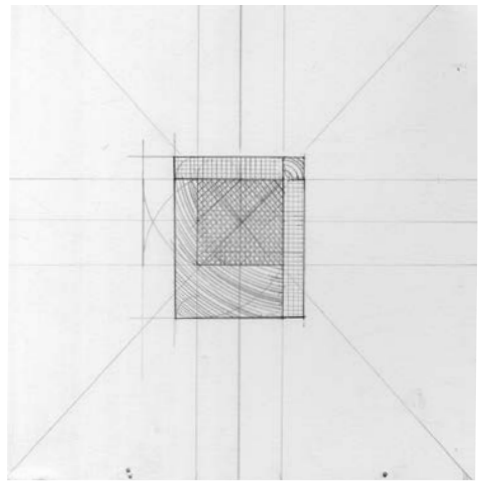
A buffer zone acts as an in-between space and one that minimizes the difference in pressure, wind exposure, and temperature of the exterior conditions against the envelope of a building. For example, an airlock entry prevents an influx of unconditioned air into a building every time the exterior door opens. Another example is a double wall in which a ventilated screen allows airflow to reduce the pressure and temperature differential against the air, thermal, moisture, and vapor layers of the wall section. A third example is that of row homes; a party wall between two units is thermally buffered from exterior conditions by the adjacent unit. End units consume more energy than other units in a series of row homes.

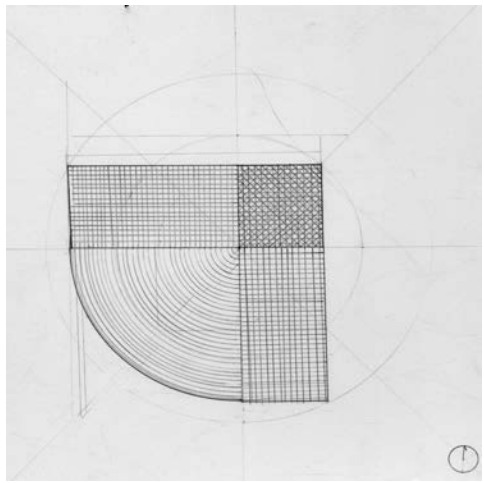
By expanding the envelope to become functional and programmatic, a new space is created that is neither fully conditioned nor entirely exposed to the exterior environment. Generally the standard of comfort in the US requires that conditioned spaces maintain a temperature between 67-76° and relative humidity (RH) between 40-60%. In this new in-between space, the standard for comfort is reconsidered, allowing for a higher temperature and RH swing. This acts as a buffer zone between the interior and exterior and also creates varied, dynamic and diverse layers of comfort and conditioned functional space.

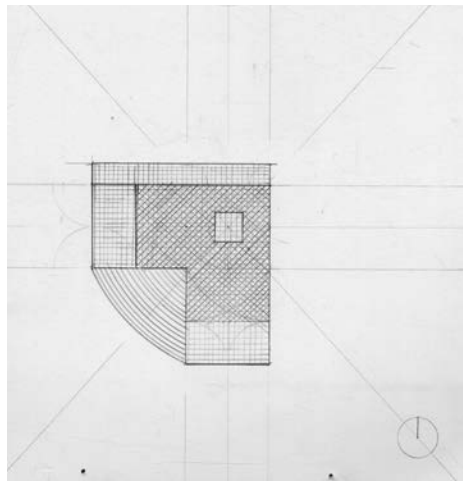
94. 

95. 

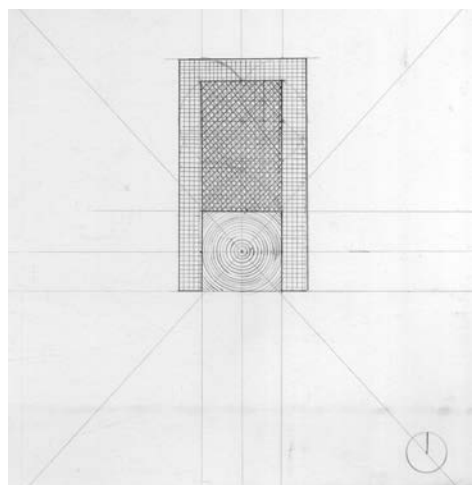




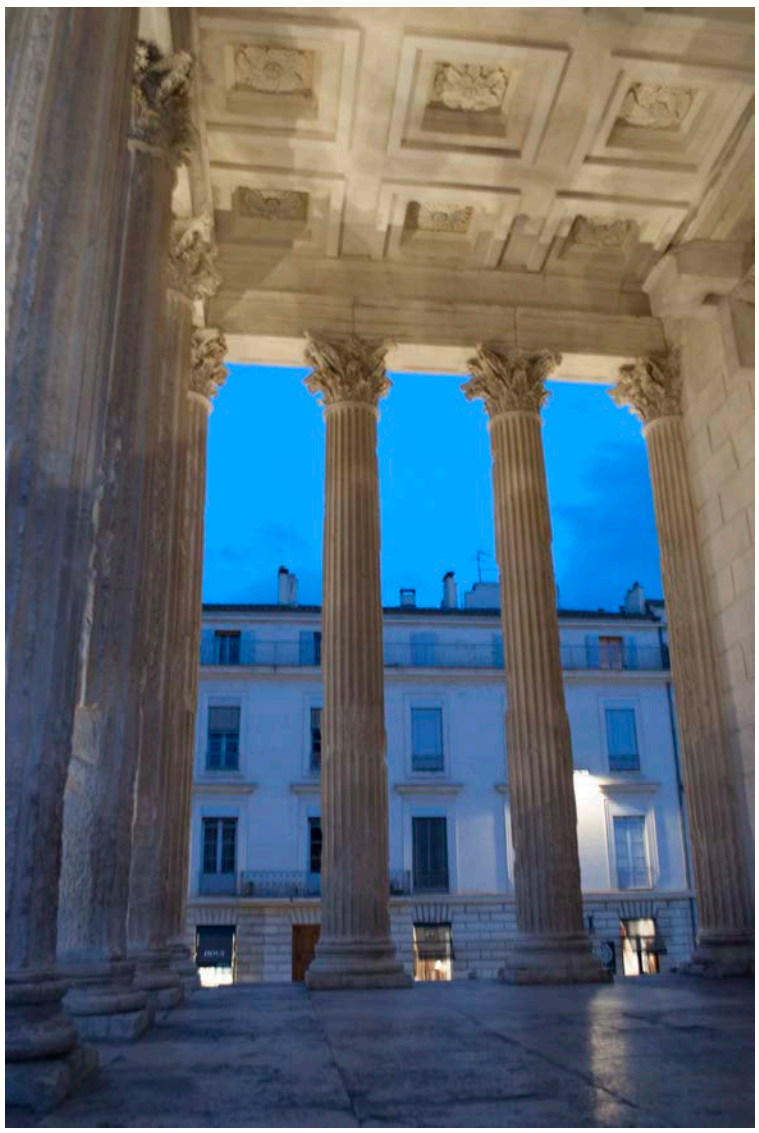


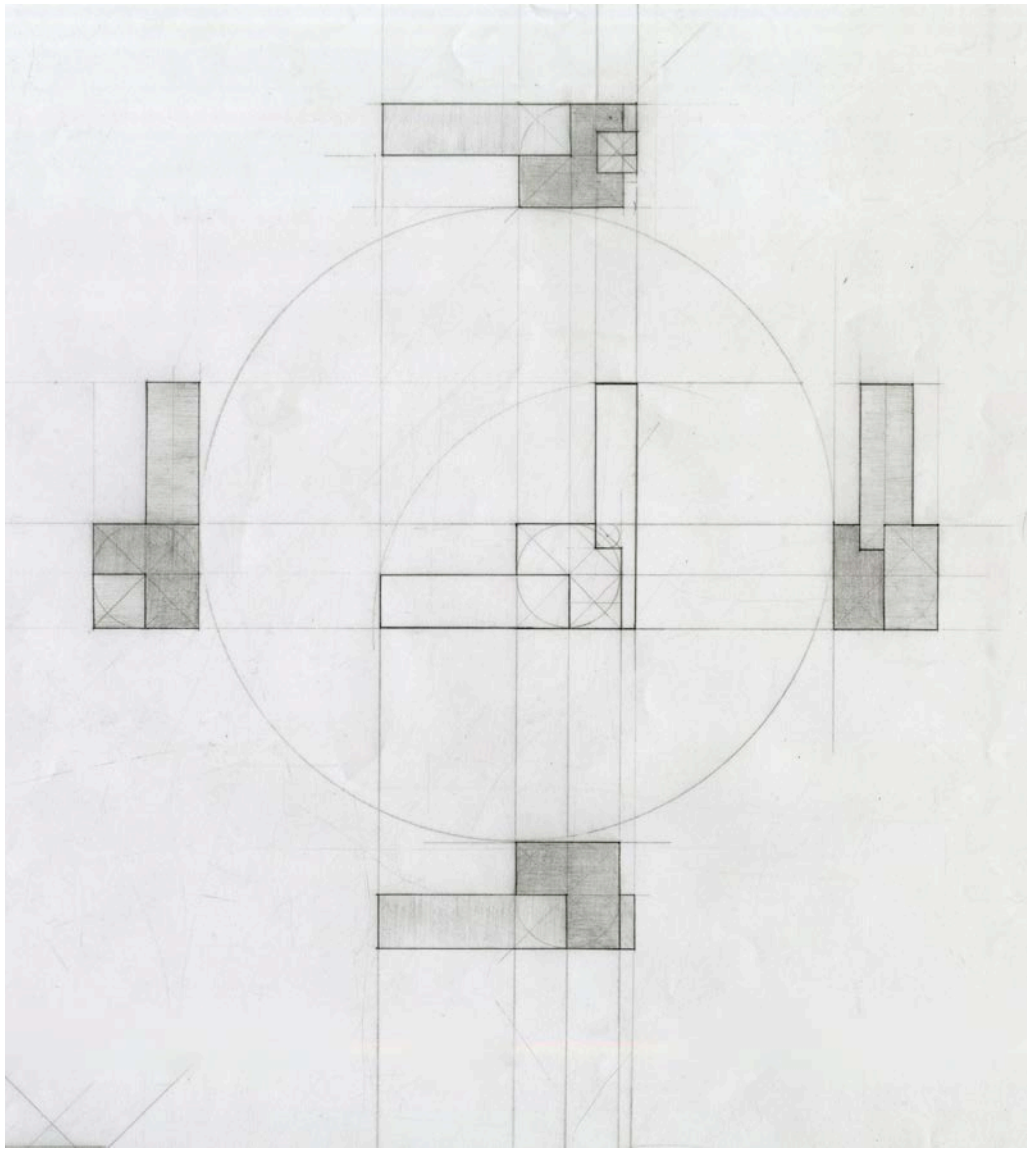


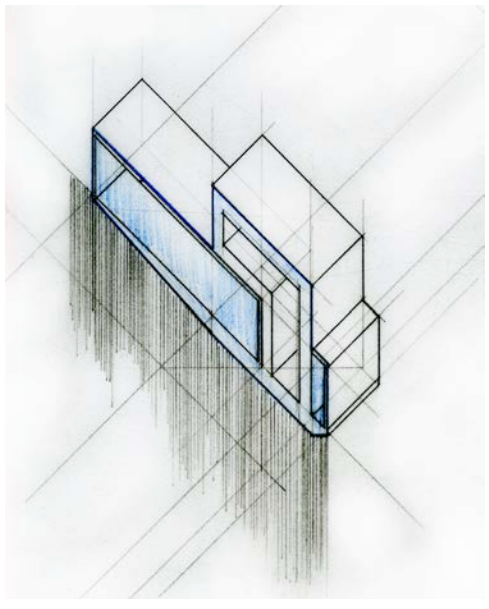
96.

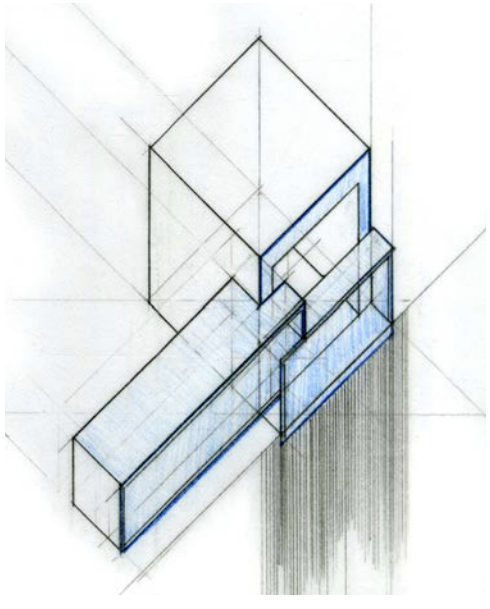


Interior	building core convenient store cafe galleries	mechanically conditioned
Between	gathering spaces stair/ corridors	passively conditioned
Exterior	plaza outdoor seating	not conditioned

97. 

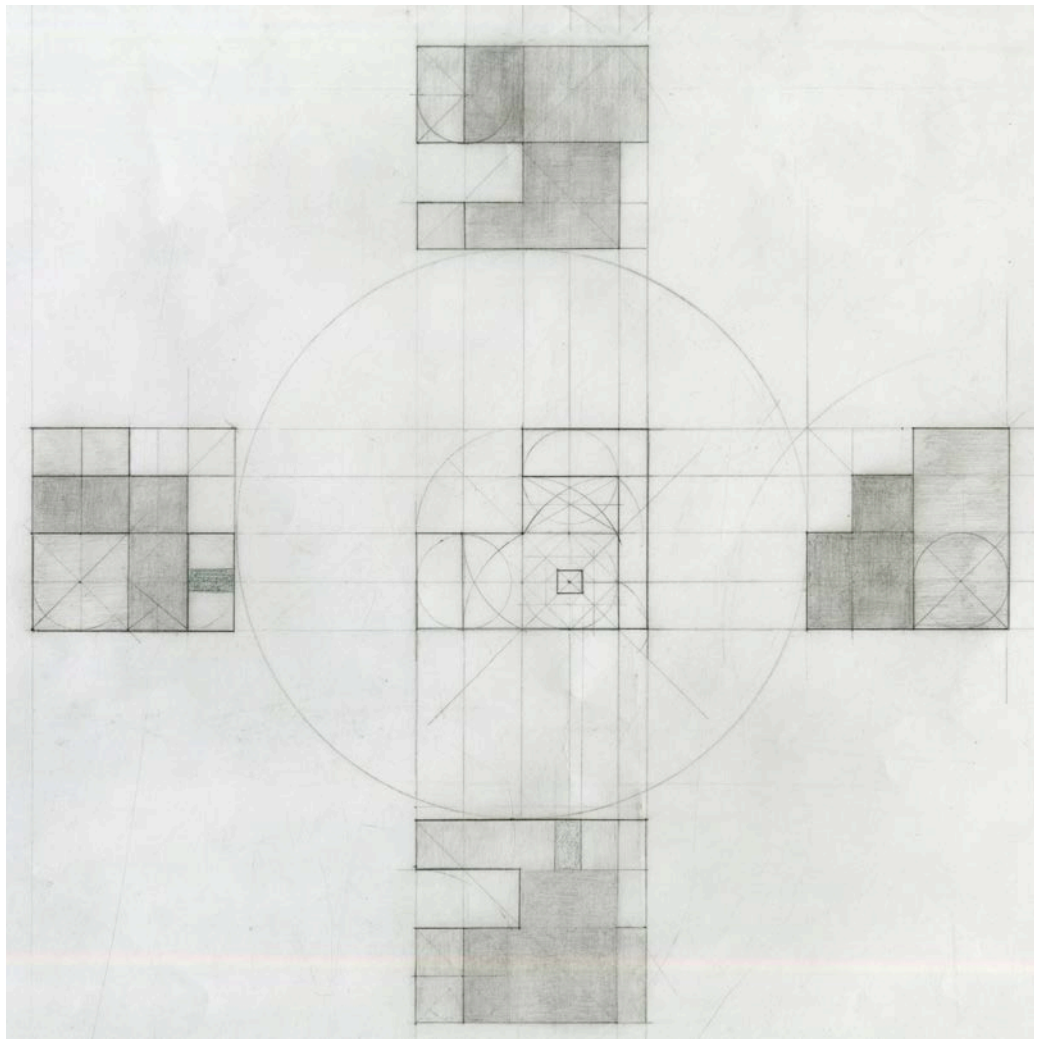


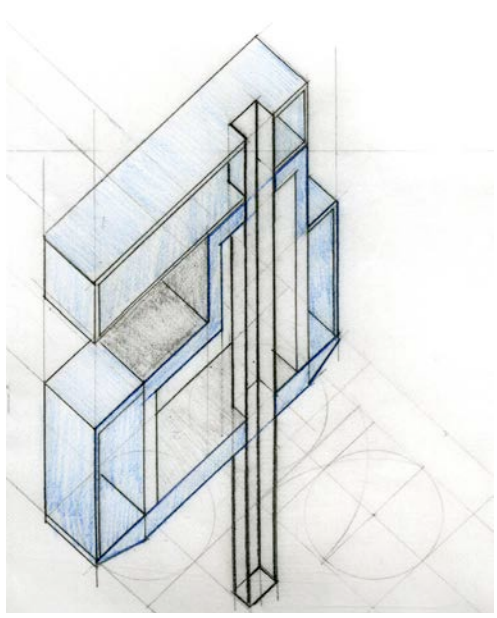


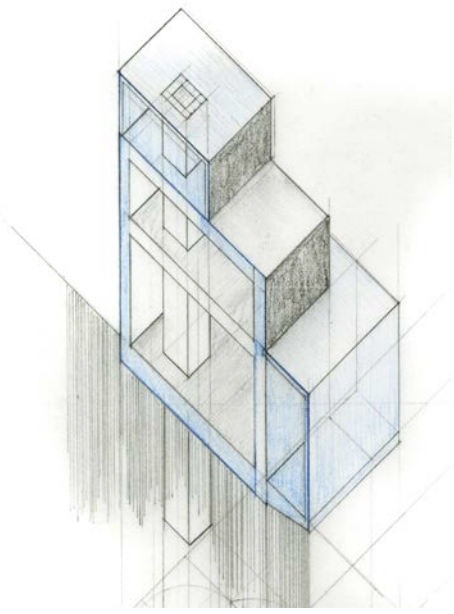


98.

L Series 01

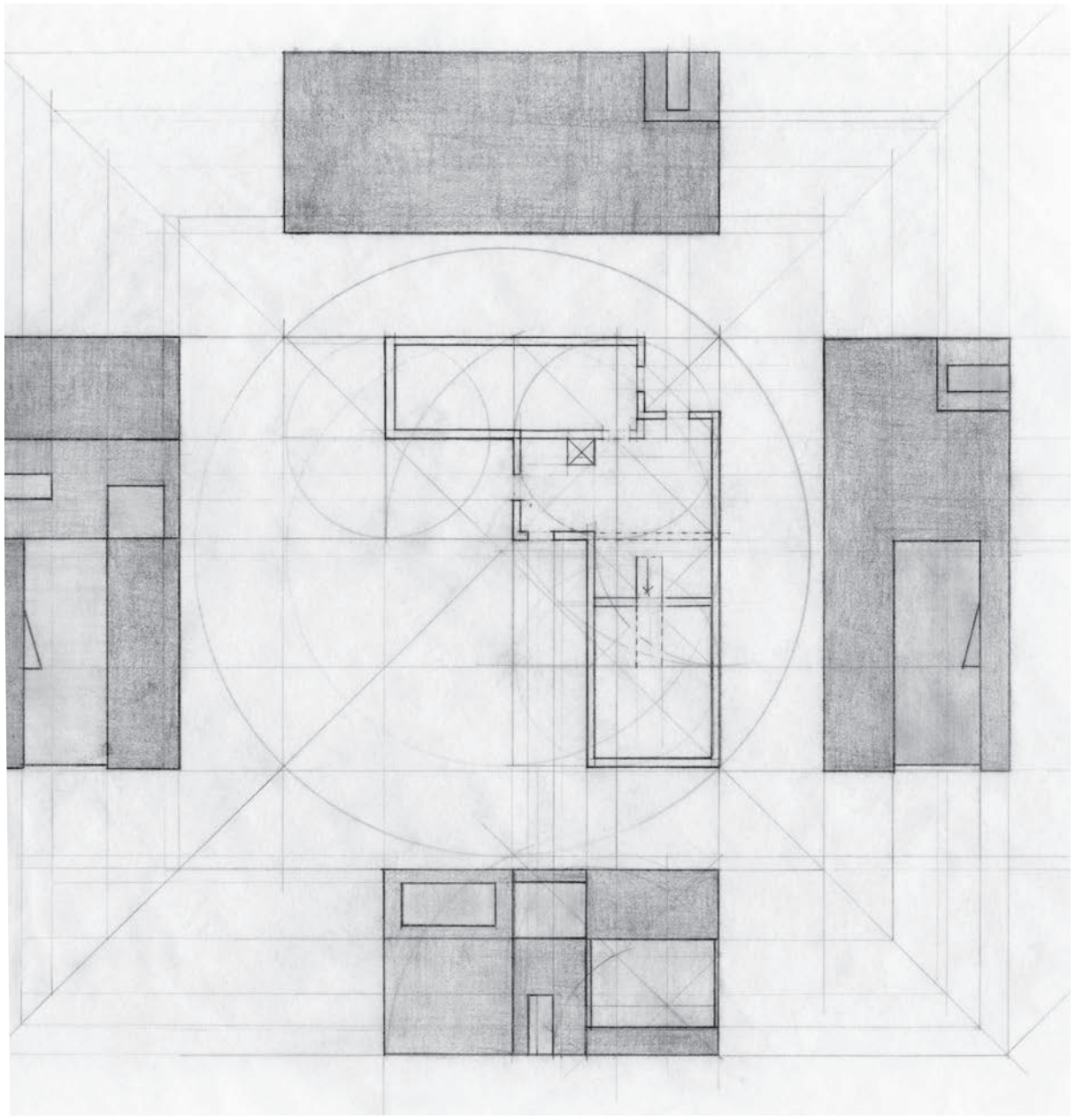




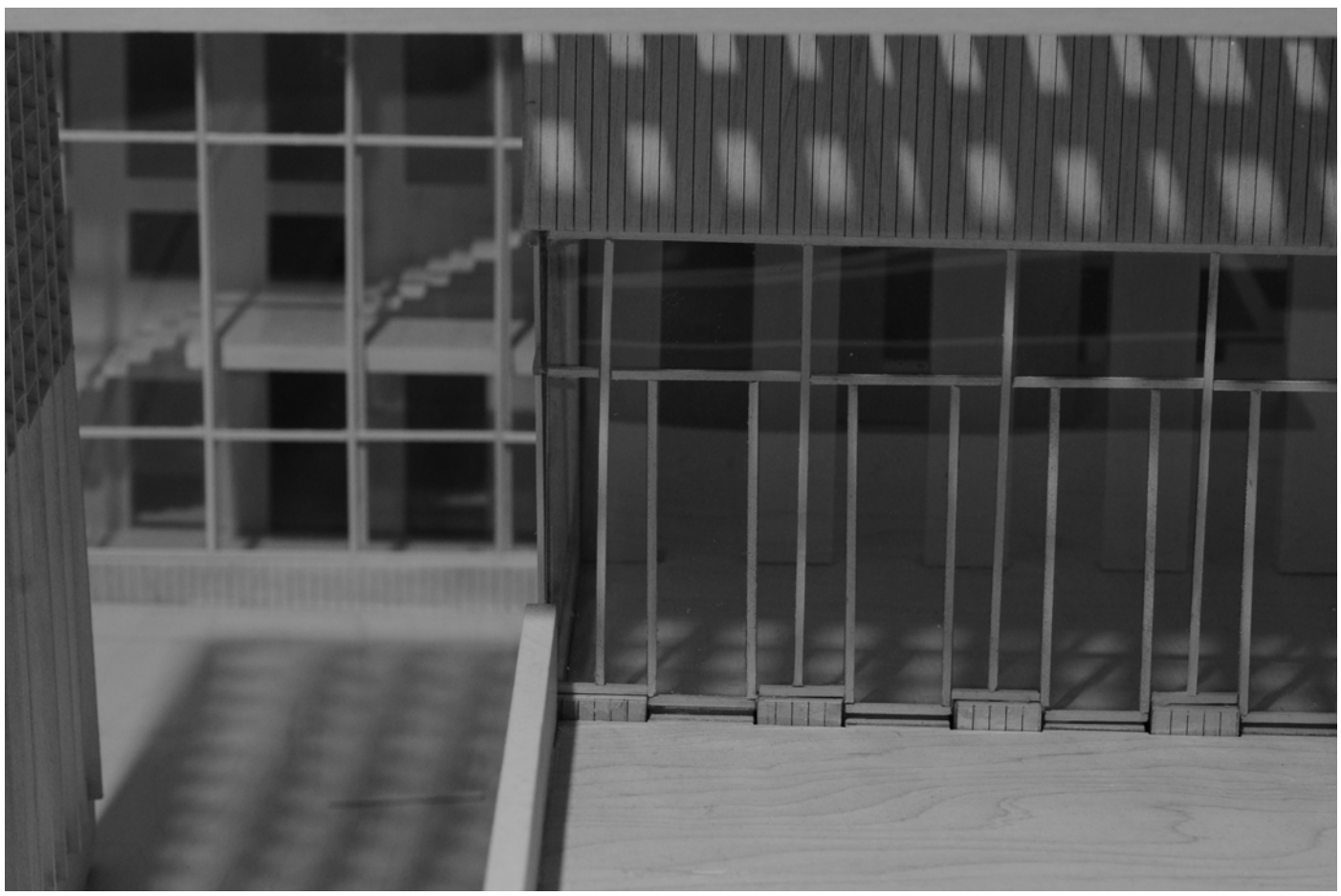


99.

L Series 02



100. L Series 03



101.

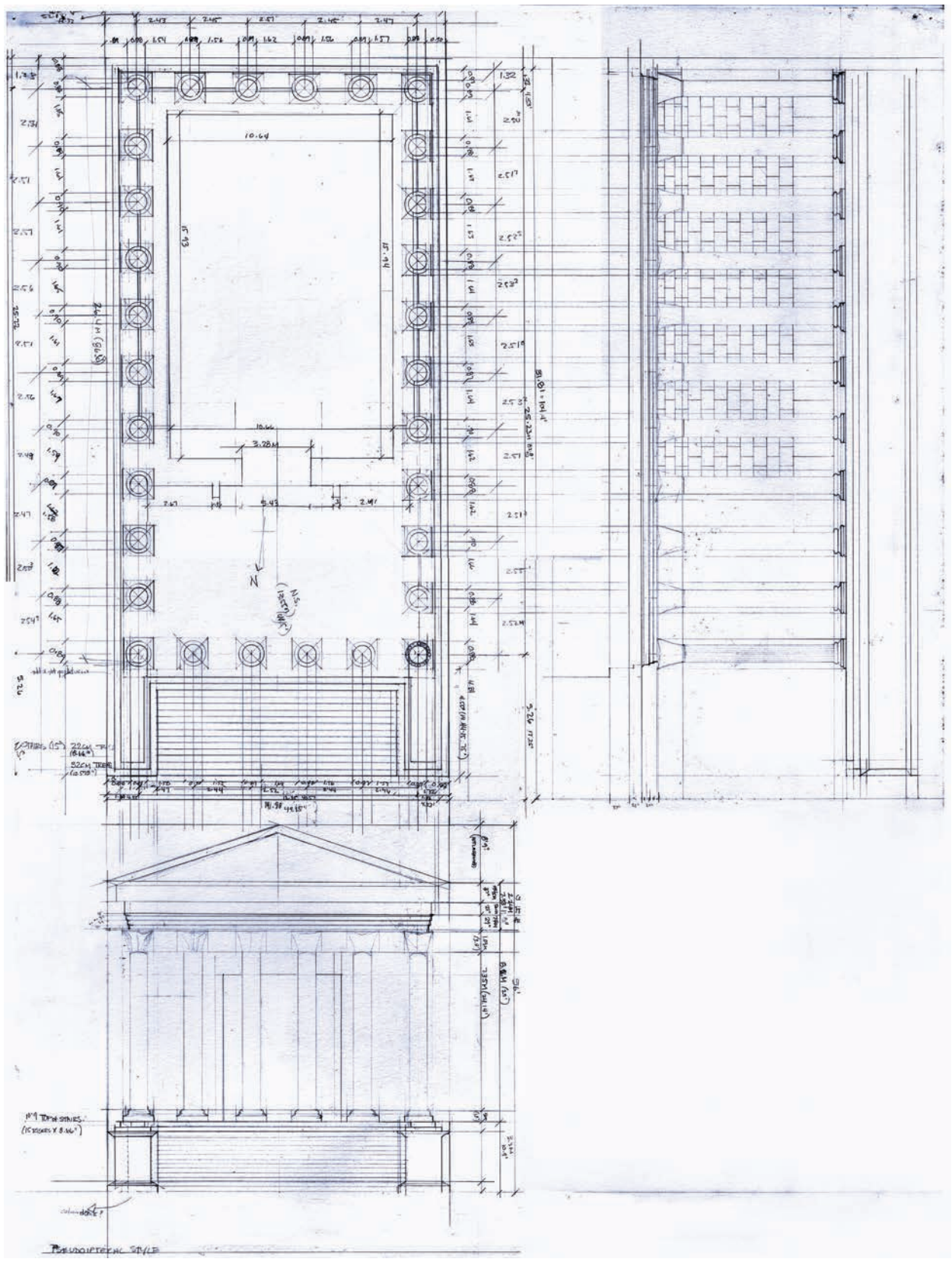
Maison Carrée

a study of proportions

"Aside from the familiar dialectic between form and function, which has played such a prominent role in the evolution of twentieth-century architecture, one may argue that the generation of form invariably involves an interplay between a further series of polarities, beginning with the fundamental opposition between tradition and innovation. As the philosopher Hans Georg Gadamer instructs us, this opposition implies a continuous discourse between the two, in which the prejudice of a given cultural legacy has to be continually reassess against a critique that stems from another 'mode of beholding'. As Georgia Warnke put it in her 1987 study of Gadamer's philosophy:

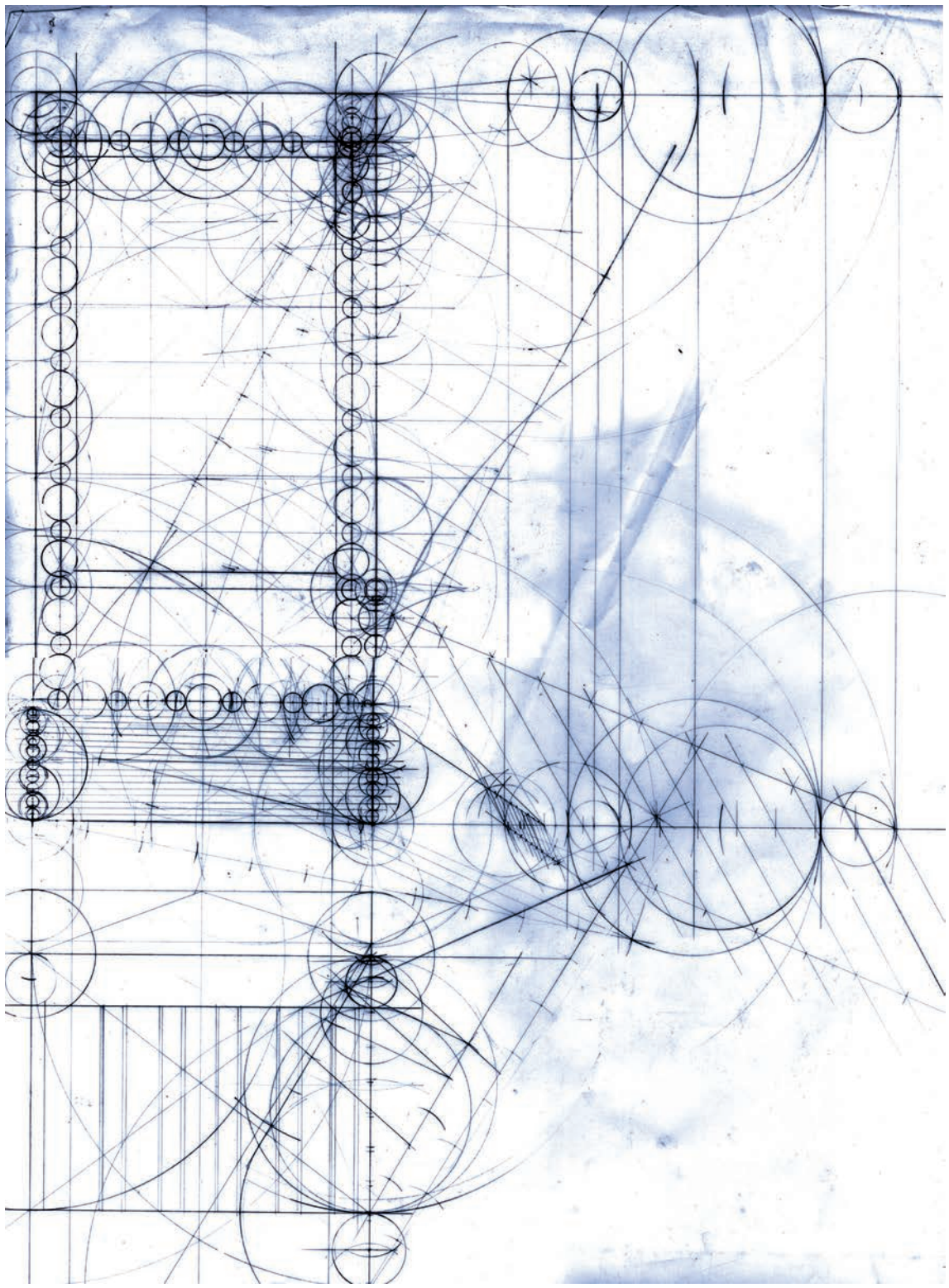
...we understand history not simply because we make it but also because it has made us; we belong to it in the sense that we inherit its experience, project a future on the basis of the situation that the past has created for us and act in the light of our understanding of this past, whether such an understanding is explicit or not."

Labour, Work, and Architecture
Collected Essays on Architecture and Design
Kenneth Frampton



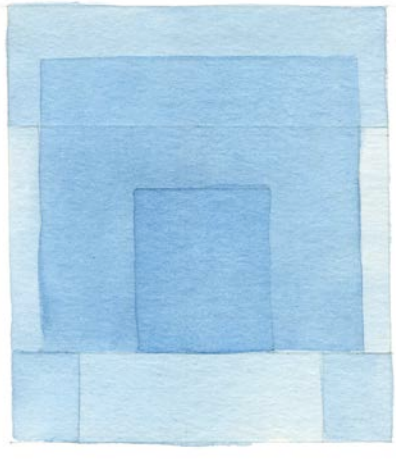
103.

Constructed plan with North and West elevations.

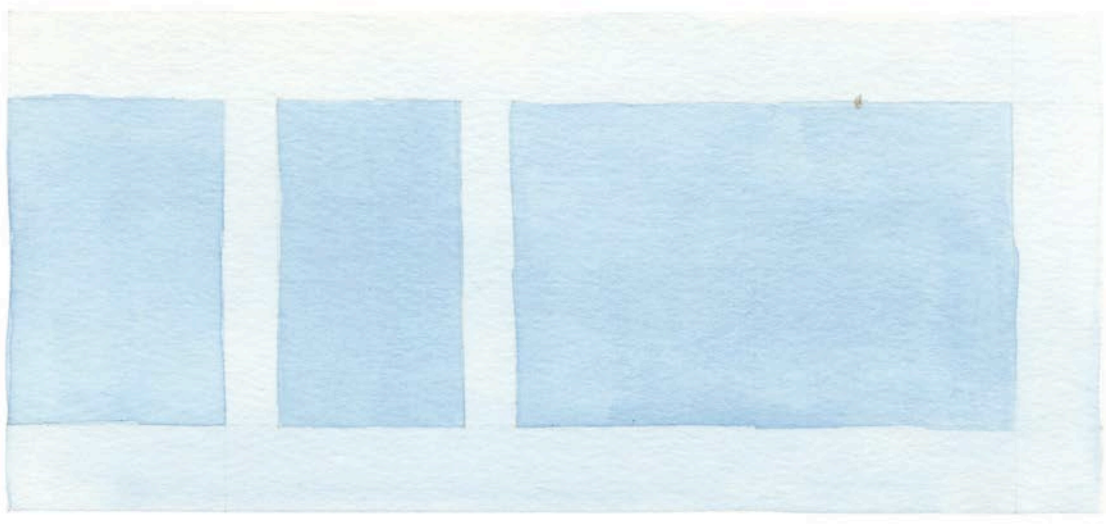


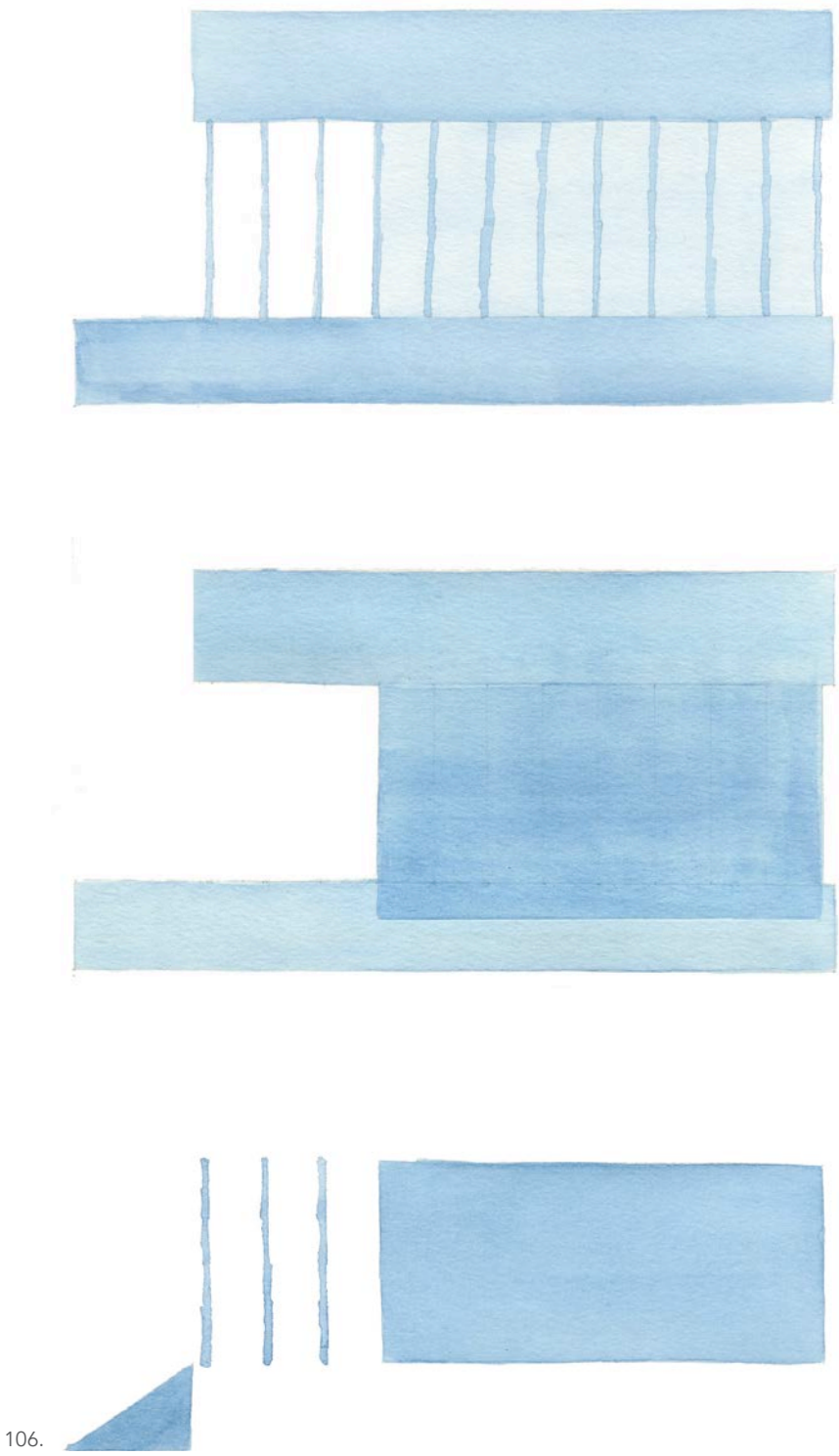
104.

Geometric construction of the plan and North elevation:
Width is forty nine feet
Length is the golden ratio of the width plus half
Height is the width set on a podium of ten feet
L x W x H = W x 2.3W x 1.14W



105.

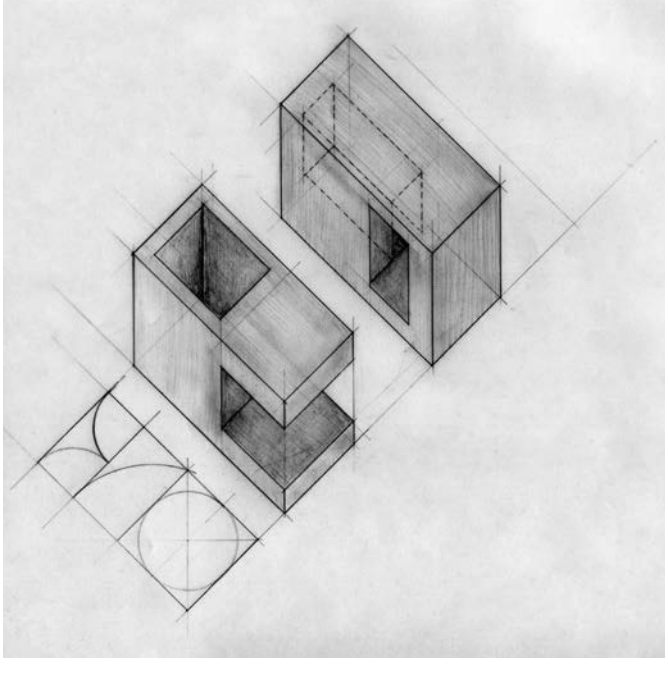


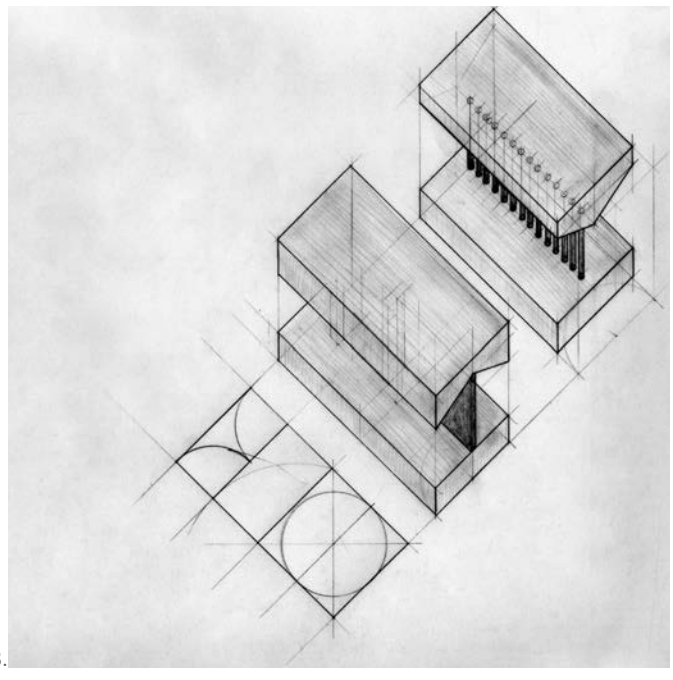


106.

Stairs	Porch	Cella
Exterior	Between	Interior

107.





108.

109.

110.

111.

112.

113. 

Energy Analysis

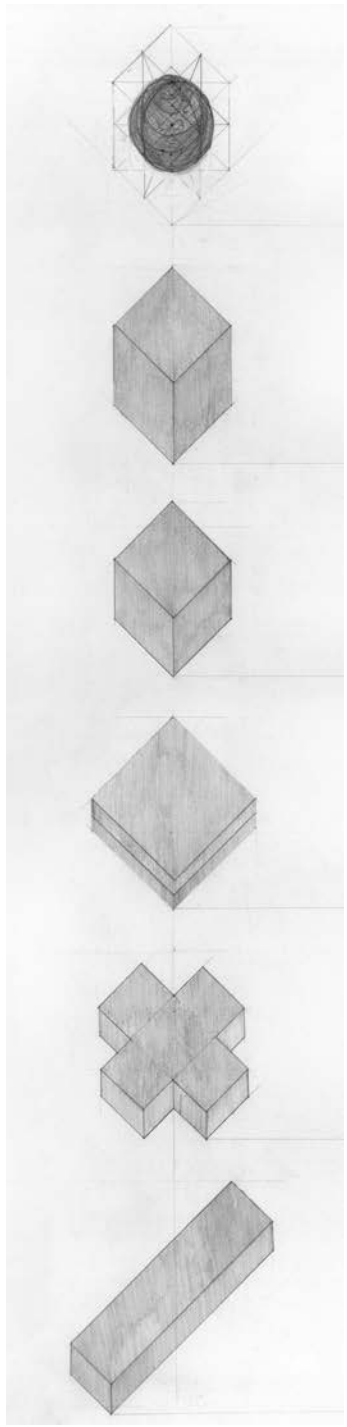
"While fabrication invariably terminated in the ancient world in either an instrument of use or an art object, it came with the emergence of empirical science to insinuate its process into the methodology of research and, with this deviation, to remove itself from the traditional teleology of artifice in favour of achieving the abstract instruments of cognition."

Kenneth Frampton
Labour, Work, and Architecture
"The Status of Man and the Status of his Objects."

Part 1:

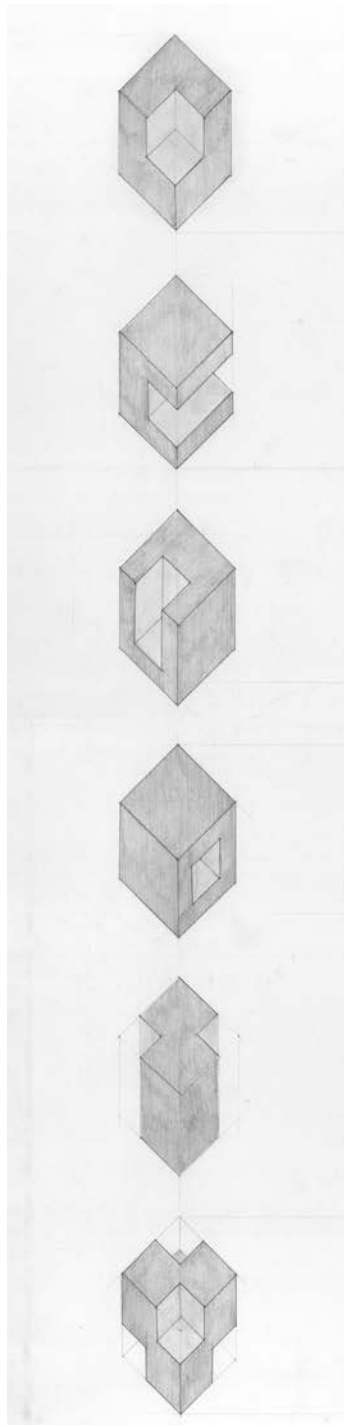
Exploratory study of energy in form

Form Type	V (ft^3)	SA (ft^2)	SA / V
sphere d=8.5	321.6	227	.705
cube 8.5x8.5x8.5	614.1	433.5	.705
cube 8.5x8.5x6	433.5	348.5	.804
cube 8.5x8.5x3	432	432	1
cross 6x4x4	432	468	1.083
rectangle 24x6x3	432	468	1.083



114.

V (ft^3)	SA (ft^2)	SA / V	Form Type
550.1	433.5	.788	cube 8.5x8.5x8.5 minus one void 4x4x4
478.1	469.5	.982	cube 8.5x8.5x8.5 minus one void 4x4x8.5
518.1	481.5	.929	cube 8.5x8.5x8.5 minus one void 4x4x6
550.1	497	.903	cube 8.5x8.5x8.5 minus one void 4x4x4
461.1	397.5	.862	cube 8.5x8.5x8.5 minus two voids 3x3x8.5
422.1	433.5	1.027	cube 8.5x8.5x8.5 minus three voids 4x4x4



115.

Exploratory studies began with the abstract study of form in relation to the measure of compactness as described in Chapter 03, Negation. New forms created through the subtractive process of negation were developed from a baseline volume of a cube 8.5 x 8.5 x 8.5 in dimension and 614.125 in volume.

Definitions of terms and equations in Part 1

Volume (V)
Total volume of an enclosed form as if it were conditioned space within the thermal envelope.

Surface Area (SA)
Total area of each plane of an enclosure including the ground plane.

Surface Area/Volume (SA/V)
Measure of compactness.

Envelope Losses (Qt)
The equation Qt = U x A x Δ T x Ft is used to calculate transmission losses through the envelope of an enclosure. Qt is in units of Btu/hr.

U Value (U)
The measure of heat transmission through a building assembly (such as a wall or window) or a given thickness of a material. In these equations the U value is in units of Btu/hr·°F·ft^2. The inverse of the U value is the R Value, or the measured amount of heat resistance of a building assembly or given thickness of a material. The following U and R values were used for complete ground, wall, and roof assemblies.

Assembly	U Value (Btu/hr·°F·ft^2)	R Value (hr·°F·ft^2/Btu)
Ground	0.047	21.3
Wall (ambient)	0.037	27
Wall (semi)	0.037	27
Roof	0.017	60

Area (A)
In the equation for Qt, the Area (A) is the surface area of each plane of the enclosure.

Temperature difference (Δ T)
The temperature difference between the interior of the enclosure and the exterior ambient temperature. For the calculations in Part 1, a temperature delta of 42°is used which is the difference between an interior temperature of 72° and an exterior temperature of 30°

Transmission loss factor (Ft)
Ft is a factor used to distinguish the transmission losses of a standard wall/roof assembly from a semi-conditioned wall/roof assembly, and from the ground assembly. A standard wall/roof assembly is exposed to the ambient outdoor conditions and does not have a factor reduction. A semi-conditioned wall/roof assembly is adjacent to void space that is passively conditioned, therefore buffered from a direct connection to ambient air which would affect the rate of thermal transmission through that assembly. For these walls a Ft reduction of 0.5 is used. The ground assembly is directly in contact with the earth and not exposed to ambient air as well. The Ft factor of 0.92 is used for ground assemblies.

Assembly	Ft
Ground	0.92
Wall (ambient)	1.0
Wall (semi)	0.5
Roof (ambient)	1.0

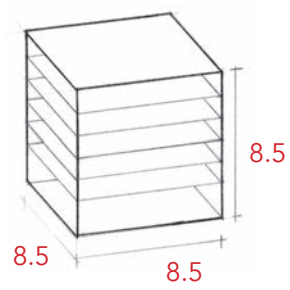
No. of Levels
Number of hypothetical levels of a given enclosure to be used in the subsequent equation SA/iCFA.

Surface Area/ Interior Conditioned Floor Area (iCFA)
Performance ratio of the surface area of an enclosure divided by the total area of all interior conditioned floors in the enclosure. This ratio becomes a more accurate way of determining the efficiency of a multi-story building. Note that the surface area used in this equation excludes the plane that meets the ground.

Series 01

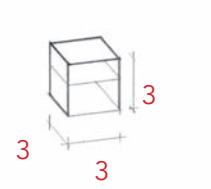
3 cubes with varying dimensions for x:
x>6
x=6
x<6

01.1



01.2

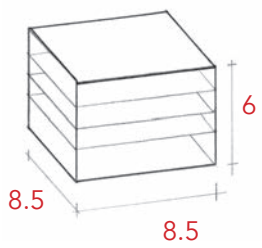
01.3



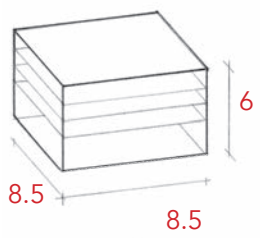
Series 02

4 cubic volumes with L=8.5, W=8.5, and varying heights and number of hypothetical levels

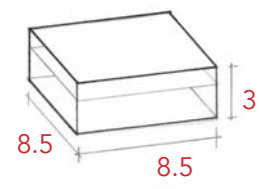
02.1



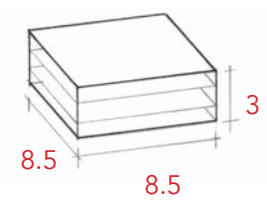
02.2



02.3



02.4



Series and form #		V (ft^3)	SA (ft^2)	$\frac{SA}{V}$	Q_t (Btu/hr)	No. of levels	$\frac{SA}{iCFA}$
Series 01	01.1	614.13	433.5	.705	569.94	6	.83
	01.2	216	216	1.00	283.98	4	1.25
	01.3	27	45	1.66	71.00	2	2.5
Series 02	02.1	433.5	348.5	.804	437.72	4	0.76
	02.2	433.5	348.5	.804	437.72	5	0.64
	02.3	217	246.5	1.14	279.05	2	1.21
	02.4	217	246.5	1.14	279.05	3	0.80

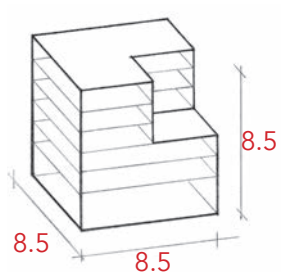
116.

The form studies above, expand on the initial study of surface area to volume (SA/V) as a measure of compactness to also include the surface area to interior conditioned floor area ratio (SA/iCFA). Series 01 demonstrates that the SA/V of a cube diminishes when the X<6. Series 02 demonstrates that the SA/iCFA becomes a more accurate method to analyze the compactness of a volume once the horizontal stratification of levels is introduced. In forms 02.1 and 02.2, the SA/V are equal but the number of levels varies by one. The form with more levels, 02.2, is more compact in terms of SA/iCFA. The same is true for the forms 02.4 and 02.3.

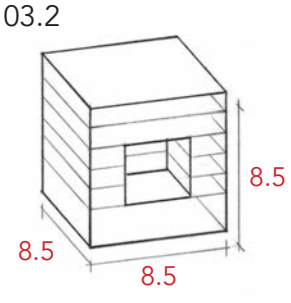
Series 03

4 cubes where x=8.5 and with cubic volume subtractions. All have 5 hypothetical levels.

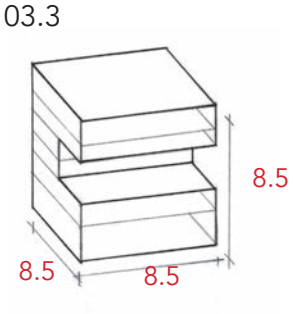
03.1



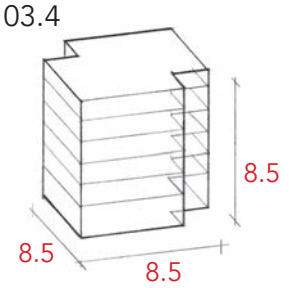
03.2



03.3



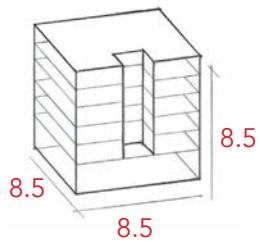
03.4



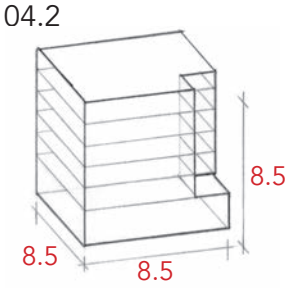
Series 04

3 cubic volumes where L=8.5, W=8.5, and Height=8.5, 6, or 3 with cubic volume subtractions at corners. For each of the three cubic volumes the same number of hypothetical levels were used in the calculations.

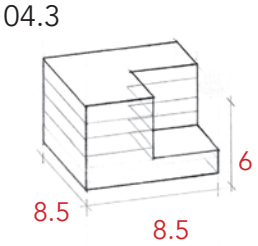
04.1



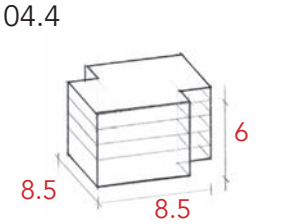
04.2



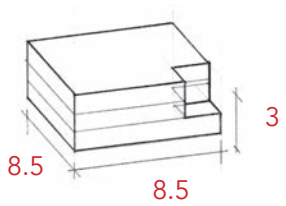
04.3



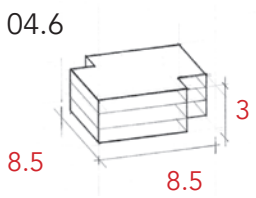
04.4



04.5



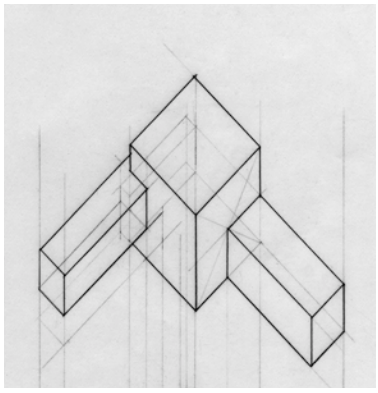
04.6



Series and form #		V (ft^3)	SA (ft^2)	$\frac{SA}{V}$	Q_t (Btu/hr)	No. of levels	$\frac{SA}{iCFA}$
Series 03	03.1	550	433.5	.788	576.16	6	0.94
	03.2	550	497.5	.905	657.05	6	1.10
	03.3	478.13	469.5	.982	644.60	6	1.20
	03.4	546.13	397.5	.728	524.08	6	1.05
Series 04	04.1	518.13	481.5	.929	610.07	6	1.16
	04.2	518.13	433.5	.837	573.67	6	1.09
	04.3	369.5	348.5	.943	419.85	4	1.15
	04.4	385.5	332.5	.863	416.92	4	1.04
	04.5	209	246.5	1.179	280.60	3	0.75
	04.6	192.7	230.5	1.196	261.99	3	0.86

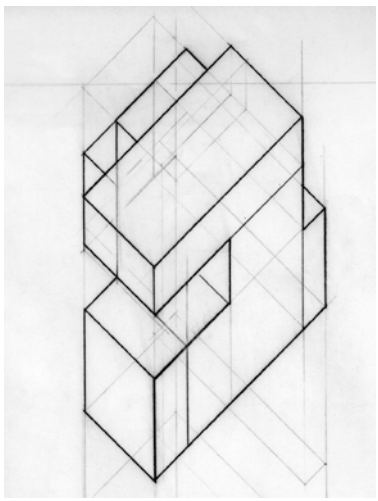
117.

Series 03 demonstrates that the process of subtraction is most effective when volume is removed from the corners compared to the middle plane of a surface. Series 04 combines the form making methods of Series 02 and 03 to look at more variations of cubic forms with subtracted voids in different scales. This series demonstrates that the same void form with a smaller height may be less compact in SA/V but more compact in SA/iCFA. This is true for the forms 03.4, 04.4, and 04.6.



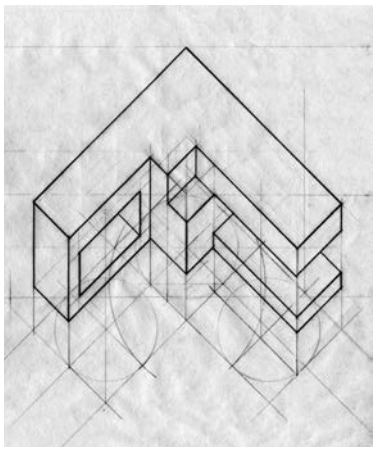
118. L Series No. 1

L Series No. 1 Configuration type	V (ft^3)	SA (ft^2)	SA / V	Q_t (Btu/hr)	No. of levels	SA / iCFA
L01.01 85'x85'x85 cube	614,125	43,350	.0705	56,994	6	0.83
L01.02 85'x85'x85' cube with voids as uncon-ditioned space	536,125	43,350	.0809	59,003	6	1.02
L01.03 85'x85'x85' cube with voids as conditioned space	1,059,625	79,750	.0753	163,936	6	1.17



119. L Series No. 2

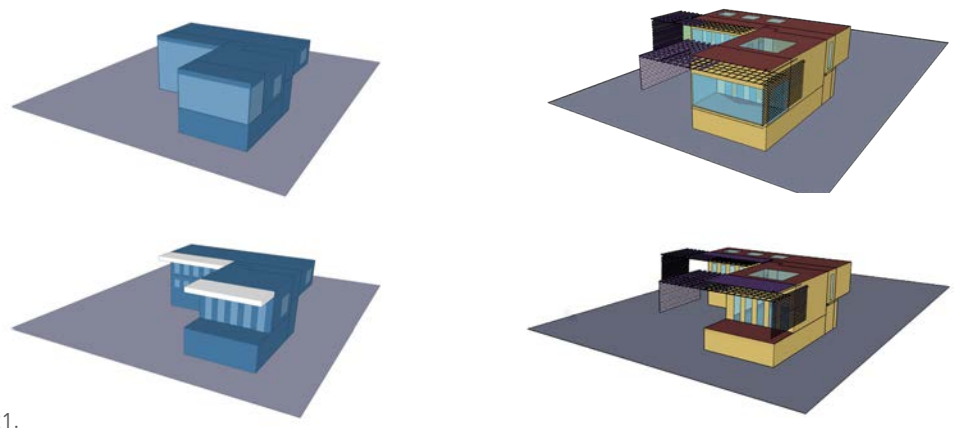
L Series No. 1 Configuration type	V (ft^3)	SA (ft^2)	SA / V	Q_t (Btu/hr)	No. of levels	SA / iCFA
L02.01 125'x130'x 85' L form	1,878,500	95,200	.0507	127,210	6	0.93
L02.02 125'x130'x 85' L form with void as unconditioned space	1,706,375	84,150	.0493	117,770	6	1.02
L02.03 125'x130'x85' L form with voids as conditioned space	2,726,375	108,775	.0399	142,377	6	1.19



120. L Series No. 3

L Series No. 1 Configuration type	V (ft^3)	SA (ft^2)	SA / V	Q_t (Btu/hr)	No. of levels	SA / iCFA
L03.01 140'x 185'x 45' L form	684,000	56,175	.0821	103,165	3	0.91
L03.02 140'x 185'x 45' L form with voids as unconditioned space	562,336	51,218	.0911	110,781	3	0.95

The L Series was developed through the drawing studies of Chapter 04, Occupy the Boundary. The series expands on the cube using subtracted void forms to create new complex forms that integrate the voids as in-between spaces. Starting with the cube, the L shape form develops and the in-between spaces become the link between the exterior plaza and interior conditioned spaces of the building.



121.

Open Studio Model	V (ft^3)	SA (ft^2)	SA/V	Q_t (Btu/hr)	No. of levels	SA/iCFA
Building 1A V2.5 with voids	74,477	11,512	.1546	21,207	3	1.69
Building 1B V3.2 without voids	59,649	12,390	.2077	15,582	3	2.22
Final Cornerstore V8.73 with voids	122,353	17,566	.1436	22,160	3	1.85
Final Cornerstore V8.73 without voids	96,622	16,698	.1728	20,908	3	2.07

As the design progressed from the abstract void forms of Part 1 to the dimensioned programmatic spaces of the final Cornerstore design, the method of exploring of energy-in-form shifted to whole building energy modeling simulations. Models were constructed in SketchUp to run Open Studio energy simulations. The calculations above were performed retroactively and not in sequential order after the L Series or before the Open Studio energy modeling of Part 2. This demonstrates a gap in the study from Part 1 to Part 2. While ideas of Part 1 influenced the progression of forms and ultimately led to the final Cornerstore design, the method of analyzing the compactness measures of SA/V and SA/iCFA became less important than other elements of the design processes such as working with proportions in relation to the study of the Mason Carrée, resolving questions regarding site context and orientation, and developing programmatic spaces in relation to the concrete structure. The energy modeling software became a tool for verification instead of a form generator as in Part 1. The calculations above show the final Cornerstore is less compact in SA/iCFA than the L Series. However, the calculations also show the potential for more complex energy analysis. The models that include the void spaces have a lower SA/V but the buildings without voids consume less energy in Qt. Looking at how the in-between spaces could blur the performance criteria in order to maximize the overall performance values became the focus of exploration. In retrospect however, the transition from the abstract study to the final design process could be better linked while addressing the other design elements.

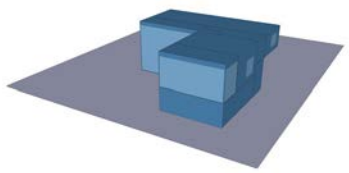
	Series and form #	V (ft^3)	SA (ft^2)	SA / V	Q_t (Btu/hr)	No. of levels	SA / iCFA
Series 01	01.1	614.13	433.5	.705	569.94	6	.83
	01.2	216	216	1.00	283.98	4	1.25
	01.3	27	45	1.66	71.00	2	2.5
Series 02	02.1	433.5	348.5	.804	437.72	4	0.96
	02.2	379	323	.804	437.72	4	0.87
	02.3	216	246.5	1.14	279.05	3	0.80
	02.4	216	246.5	1.14	279.05	2	1.21
Series 03	03.1	550	433.5	.788	576.16	6	0.94
	03.2	550	497.5	.905	657.05	6	1.10
	03.3	478.13	469.5	.982	644.60	6	1.21
	03.4	546.13	417.5	.728	524.08	6	0.92
Series 04	04.1	518.13	481.5	.929	610.07	6	1.16
	04.2	518.13	457.5	.837	573.67	6	1.09
	04.3	333.4	323	.943	419.85	4	1.04
	04.4	337.3	315	.863	416.92	4	0.95
	04.5	347	254	1.179	280.60	3	0.94
	04.6	192.7	238.5	1.196	261.99	3	0.86
Series L01	L01.01	614,125	43,350	.0705	56,994	6	0.83
	L01.02	536,125	43,350	.0809	59,003	6	1.02
	L01.03	1,059,625	79,750	.0753	163,936	6	1.17
Series L02	L02.01	1,878,500	95,200	.0507	127,210	6	0.93
	L02.02	1,706,375	84,150	.0493	117,770	6	1.02
	L02.03	2,726,375	108,775	.0399	142,377	6	1.19
Series L03	L03.01	684,000	56,175	.0821	103,165	3	0.91
	L03.02	562,336	51,218	.0911	110,781	3	0.95
OS series	V2.5	74,477	11,512	.1546	21,207	3	1.69
	V3.2	59,649	12,3900	.2077	15,582	3	2.22
	V8.73 w/voids	122,353	17,566	.1436	22,160	3	1.85
	V8.73 wo/voids	96,622	16,698	.1728	20,908	3	2.07

The chart above summarizes the calculations of the Part 1 series as well as the calculations of the OS series using the same methods.

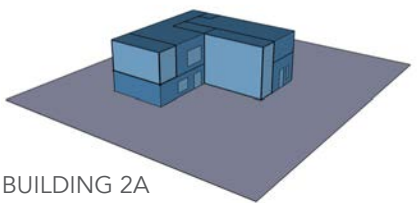
Part 2:

Preliminary study of energy in form, site orientation, and thermal envelope for the Cornerstore design

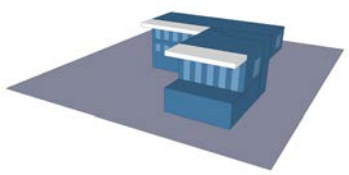
ORIENTATION AND MODEL TYPES



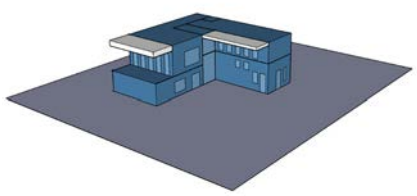
BUILDING 1A



BUILDING 2A



BUILDING 1B



BUILDING 2B

122.

OPEN STUDIO MODELING GOALS (06.18.18)

1. Compare 2 different building orientations:

   Building 01 Stair/patio facing SE, adjacent to MLK Ave.

   Building 02 Stair/patio facing SW, adjacent to Elementary School.

2. Compare buildings 01 and 02 modeled with and without the stair and patio included as thermal zones:

   Buildings 01A, 02A Stair and patio as conditioned thermal zones

   Buildings 01B, 02B Stair and patio not included as thermal zones. Instead a shading device covers the footprint of these areas

3. Evaluate exterior envelope material construction sets:

   ASHRAE 90.1 2010 Construction Set (a default provided by OS)

   EOS Construction Set (the VT design for the 2018 DOE RTNZ competition)

   Best Set (developed through this modeling)

CONSTRUCTION SETS

Assembly Type	R Value (hr·°F·ft²/Btu) ASHRAE	EOS	BEST SET
Exterior Walls	9	38	21
Roof	21	44	43 IEAD
Exterior Floor	0	17	17
Exterior Ground Wall	0	17	17
Exterior Ground Floor	0	17	0
Windows	1.82	3.47	3.472

As briefly described in Chapter 2, A Place for the DC Cornerstore, energy modeling began early in the design process using the general parameters of the site location, the L shape building form, the general massing and volume of each programmatic space, and the two building orientations under consideration.

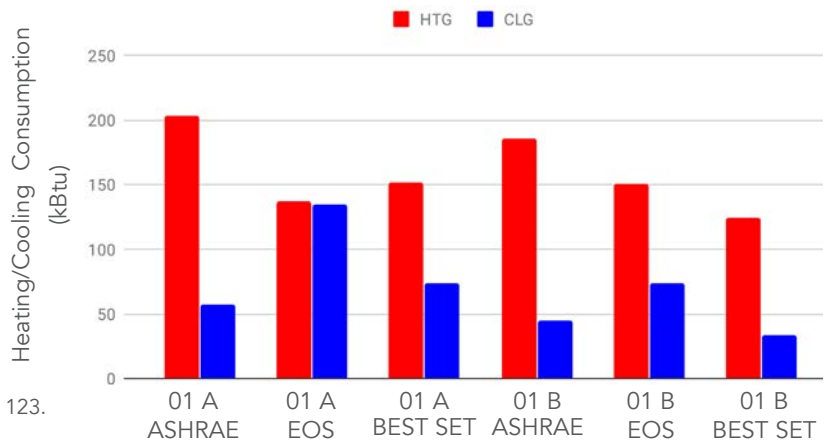
Models were constructed in SketchUp using a plug-in to create an Open Studio (OS) compatible files. Open Studio V2.4.0 was used to run Energy Plus V8.8 whole building energy simulations over the course of one year, using energy plus weather files for Washington DC, which is in ASHRAE Climate Zone 4A. Open Studio provides detailed results of the energy consumption for the heating, cooling, ventilation, lighting, plug, and process loads.

In the preliminary energy simulations of Part 2, default schedules were used for lighting, plug, and process loads based on the Retail standard building type default as provided by Open Studio. Ideal air loads were used for HVAC systems which is also an OS default setting. The building was constructed by the volume of each programmatic space and were organized into eight thermal zones.

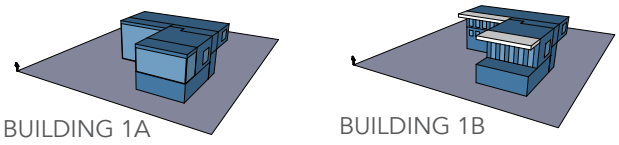
There were three goals of this initial modeling series. First to compare the two building orientations in order to make an informed decision about the site layout in relation to MLK Ave and the surrounding area. The second was to compare modeling building with the in-between spaces (ie, stair/corridor and lower level patio) as conditioned thermal zones versus exterior to the thermal envelope. The purpose of this goal was to understand the conditions in these zones and their impact on the overall the heating and cooling loads for the building. The third goal was to evaluate different exterior envelope construction sets for thermal performance in order to develop a wall section for the exterior envelope of the building.

OPEN STUDIO THERMAL ZONES

TZ1	Convenient Store	TZ5	Lower Level Gallery
TZ2	Cafe	TZ6	Lower Level Patio
TZ3	Lobby	TZ7	Upper Level Lobby
TZ4	Stair/Corridor	TZ8	Upper Level Gallery



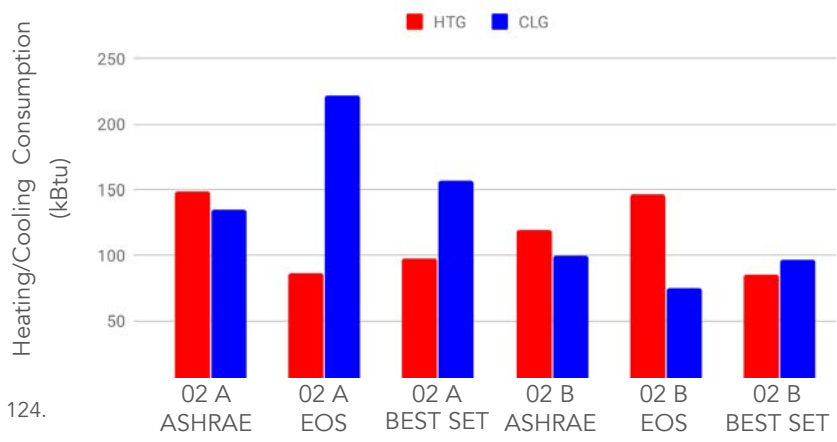
123.



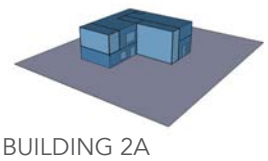
BUILDING 1A

BUILDING 1B

Orientation Type	01	01	01	01	01	01
ModelType	A	A	A	B	B	B
Construction Set	ASHRAE	EOS	BEST SET	ASHRAE	EOS	BEST SET
Annual HTG (kBtu/yr)	203	137	151	186	150	34
Annual CLG (kBtu/yr)	57	135	74	45	74	125
Annual Total	260	272	225	231	225	159



124.



BUILDING 2A

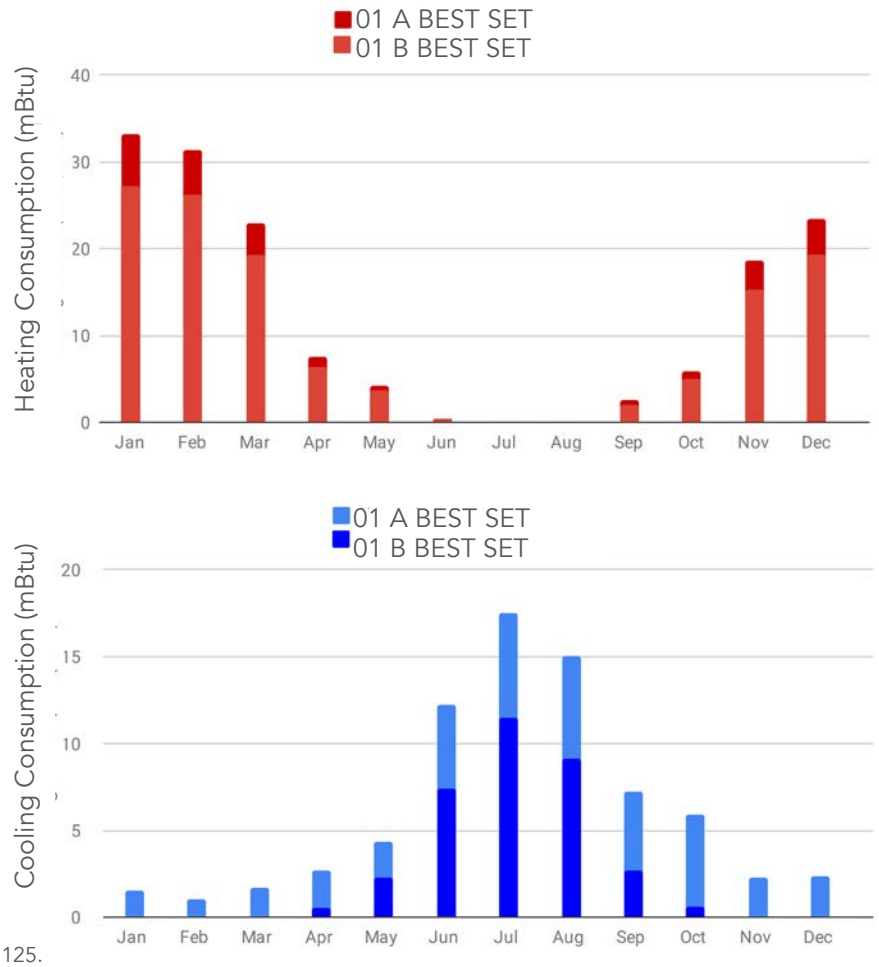
BUILDING 2B

Orientation Type	02	02	02	02	02	02
ModelType	A	A	A	B	B	B
Construction Set	ASHRAE	EOS	BEST SET	ASHRAE	EOS	BEST SET
Annual HTG (kBtu/yr)	148	86	98	119	146	85
Annual CLG (kBtu/yr)	135	222	157	100	75	97
Annual Total	283	308	255	219	221	183

The results of the energy modeling simulations demonstrate that building 01 models had lower total annual heating and cooling loads than building 02 models. For both orientation types, 01 and 02, the models that excluded the stair and patio spaces, type B, had lower cooling and heating loads. There is also improved performance for both building types when the Best Set construction set was used.

The results also demonstrate that the orientation affects the balance between the heating and cooling loads. Building 01 had higher heating loads than building 02 whereas building 02 had higher cooling loads than building 01. Building 01 naturally shades the plaza side from morning summer sun exposure but benefits from afternoon and evening sun in the winter. Building 02 gets full morning summer sun exposure and shades the plaza side naturally from afternoon and evening sun throughout the year.

The modeling shows that in-between zones have higher heat gains and losses compared to the rest of the building. Therefore when the building is modeled without these zones included, the overall energy performance improves. This is due to the high window to wall ratio, 70%, in these zones compared to the overall building win/wall ratio of 34%. These zones also increase the annual cooling demand in both building scenarios because they require cooling in the winter months during hours of peak sun exposure.



125.

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
01 A	BEST SET	HTG	33.22	31.36	22.95	7.56	4.29	0.44	0.09	0.13	2.56	5.88	18.63	23.41	150.52
		CLG	1.51	1.01	1.67	2.7	4.34	12.22	17.5	15.01	7.25	5.93	2.25	2.36	73.75
01 B	BEST SET	HTG	27.3	26.5	19.34	6.44	3.64	0.40	0.01	0.14	2.11	5.11	15.22	19.23	125.18
		CLG	0	0	0	0.55	2.24	7.24	11.45	9.11	2.66	0.64	0.02	0	34.09

Comparing the difference in the two modeling types, A and B, demonstrates that the in-between spaces of the stair/corridor and patio contribute significantly to the overall annual cooling loads. The graphs above shows the results for the two modeling types A and B, of building 01, using the best set construction set. For the cooling consumption graph, the light blue indicates cooling loads of building 01, A, Best Set and the dark blue indicates cooling loads for building 01,B, Best Set. The difference between the two cooling loads illustrates the excess heat in the in-between zones during the shoulder and winter months. Instead of cooling these zones, this excess heat can be redirected to other zones in the building to offset their heating requirements. Over the course of the year, the in-between zones could offset 9% of the heating demands in adjacent zones during the fall/winter months of January, February, March, November, and December. During the spring/summer months of April, May, June, July, August, and September, the in-between zones account for almost 51% of the cooling loads. These loads could be offset by increasing the design temperature for these zones to reduce the amount of cooling required, by using isolated natural ventilation in this zones to remove excess heat, and leaving the concrete slab floors uninsulated in order for them to function as a heat sink.

BUILDING 1A

OS Model V2.5 ASHRAE CS

Temperature	(Table values below represent % of hours in a given year in each temperature range)										
Zone	< 56 °F	56-61 °F	61-66 °F	66-68 °F	68-70 °F	70-72 °F	72-74 °F	74-76 °F	76-78 °F	78-83 °F	83-88 °F
TZ 1 - Convenient Store	0%	15%	10%	3%	41%	10%	8%	13%	0%	0%	0%
TZ 2 - Cafe	0%	16%	9%	3%	42%	9%	8%	13%	0%	0%	0%
TZ 3 - Lobby	0%	14%	11%	3%	48%	10%	9%	5%	0%	0%	0%
TZ 4 - Stair/Corridor	0%	21%	6%	2%	31%	7%	7%	25%	1%	0%	0%
TZ 5 - Lower Level Gallery	0%	16%	9%	3%	38%	9%	8%	17%	0%	0%	0%
TZ 6 - Lower Level Patio	0%	21%	6%	2%	25%	7%	6%	31%	1%	0%	0%
TZ 7 - Upper Level Lobby	0%	12%	9%	3%	39%	7%	7%	19%	3%	1%	0%
TZ 8 - Upper Level Gallery	0%	16%	8%	2%	36%	6%	6%	22%	2%	1%	0%

OS Model V2.5 EOS CS

Temperature	(Table values below represent % of hours in a given year in each temperature range)										
Zone	< 56 °F	56-61 °F	61-66 °F	66-68 °F	68-70 °F	70-72 °F	72-74 °F	74-76 °F	76-78 °F	78-83 °F	83-88 °F
TZ 1 - Convenient Store	0%	12%	8%	2%	33%	6%	6%	26%	4%	2%	0%
TZ 2 - Cafe	0%	14%	7%	2%	33%	6%	6%	25%	3%	3%	0%
TZ 3 - Lobby	0%	9%	10%	3%	40%	6%	5%	21%	4%	1%	0%
TZ 4 - Stair/Corridor	0%	18%	6%	2%	22%	6%	6%	36%	2%	2%	0%
TZ 5 - Lower Level Gallery	0%	12%	8%	2%	30%	6%	6%	28%	4%	3%	0%
TZ 6 - Lower Level Patio	0%	17%	5%	2%	16%	5%	5%	43%	3%	3%	1%
TZ 7 - Upper Level Lobby	0%	6%	11%	4%	37%	7%	5%	23%	5%	2%	0%
TZ 8 - Upper Level Gallery	0%	12%	8%	2%	33%	6%	6%	26%	4%	3%	0%

OS Model V2.5 BEST SET

Temperature	(Table values below represent % of hours in a given year in each temperature range)										
Zone	< 56 °F	56-61 °F	61-66 °F	66-68 °F	68-70 °F	70-72 °F	72-74 °F	74-76 °F	76-78 °F	78-83 °F	83-88 °F
TZ 1 - Convenient Store	0%	13%	10%	3%	39%	11%	8%	15%	0%	0%	0%
TZ 2 - Cafe	0%	17%	9%	3%	40%	9%	7%	15%	0%	0%	0%
TZ 3 - Lobby	0%	10%	13%	4%	48%	11%	9%	5%	0%	0%	0%
TZ 4 - Stair/Corridor	0%	17%	7%	2%	24%	7%	7%	33%	2%	1%	0%
TZ 5 - Lower Level Gallery	0%	14%	9%	3%	36%	9%	8%	20%	1%	0%	0%
TZ 6 - Lower Level Patio	0%	19%	6%	2%	23%	7%	6%	34%	1%	1%	0%
TZ 7 - Upper Level Lobby	0%	8%	12%	4%	39%	7%	8%	19%	3%	1%	0%
TZ 8 - Upper Level Gallery	0%	14%	8%	2%	34%	7%	7%	24%	2%	1%	0%

BUILDING 1B

OS Model V3.2 ASHRAE CS

Temperature	(Table values below represent % of hours in a given year in each temperature range)										
Zone	< 56 °F	56-61 °F	61-66 °F	66-68 °F	68-70 °F	70-72 °F	72-74 °F	74-76 °F	76-78 °F	78-83 °F	83-88 °F
TZ 1 - Convenient Store	0%	15%	9%	2%	39%	8%	8%	17%	1%	0%	0%
TZ 2 - Cafe	0%	16%	9%	2%	39%	8%	8%	16%	1%	0%	0%
TZ 3 - Lobby	0%	14%	10%	3%	45%	8%	9%	10%	0%	0%	0%
TZ 5 - Lower Level Gallery	0%	16%	8%	2%	37%	7%	7%	20%	2%	0%	0%
TZ 7 - Upper Level Lobby	0%	13%	8%	3%	29%	7%	7%	28%	3%	3%	0%
TZ 8 - Upper Level Gallery	0%	16%	7%	2%	36%	5%	6%	22%	3%	2%	0%
TZ 6 - Lower Level Patio	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TZ 4 - Stair/Corridor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

OS Model V3.2 EOS CS

Temperature	(Table values below represent % of hours in a given year in each temperature range)										
Zone	< 56 °F	56-61 °F	61-66 °F	66-68 °F	68-70 °F	70-72 °F	72-74 °F	74-76 °F	76-78 °F	78-83 °F	83-88 °F
TZ 1 - Convenient Store	0%	12%	8%	2%	34%	6%	6%	26%	4%	2%	0%
TZ 2 - Cafe	0%	14%	7%	2%	33%	6%	6%	25%	3%	3%	0%
TZ 3 - Lobby	0%	9%	10%	3%	40%	5%	6%	22%	4%	1%	0%
TZ 5 - Lower Level Gallery	0%	14%	7%	2%	32%	6%	6%	27%	4%	3%	0%
TZ 7 - Upper Level Lobby	0%	7%	10%	3%	26%	8%	7%	31%	5%	3%	0%
TZ 8 - Upper Level Gallery	0%	13%	8%	2%	34%	5%	5%	25%	4%	3%	0%
TZ 6 - Lower Level Patio	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TZ 4 - Stair/Corridor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

OS Model V3.2 BEST SET

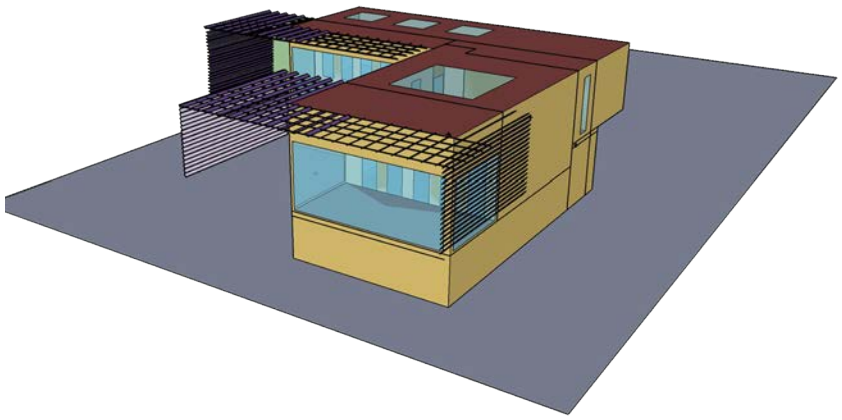
Temperature	(Table values below represent % of hours in a given year in each temperature range)										
Zone	< 56 °F	56-61 °F	61-66 °F	66-68 °F	68-70 °F	70-72 °F	72-74 °F	74-76 °F	76-78 °F	78-83 °F	83-88 °F
TZ 1 - Convenient Store	0%	16%	10%	3%	40%	10%	8%	14%	0%	0%	0%
TZ 2 - Cafe	0%	17%	9%	3%	40%	9%	7%	14%	0%	0%	0%
TZ 3 - Lobby	0%	12%	12%	4%	48%	11%	9%	5%	0%	0%	0%
TZ 5 - Lower Level Gallery	0%	16%	9%	3%	37%	9%	8%	19%	1%	0%	0%
TZ 7 - Upper Level Lobby	0%	9%	10%	3%	27%	8%	9%	30%	3%	1%	0%
TZ 8 - Upper Level Gallery	0%	15%	8%	2%	35%	7%	7%	23%	2%	1%	0%
TZ 6 - Lower Level Patio	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TZ 4 - Stair/Corridor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

126.

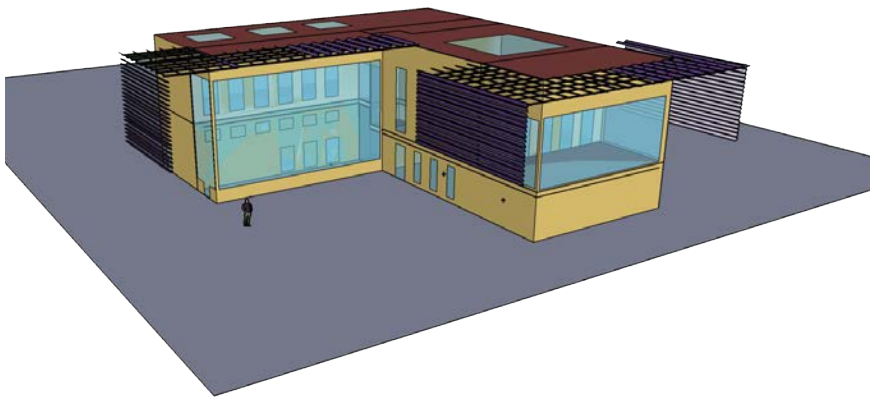
The Open Studio results above shows the percentage of hours in a given year in each temperature range for the 8 thermal zones of building 01. The values highlighted in red indicate the highest percentage for each thermal zone and the values highlighted in yellow indicate the second highest percentage.

Part 3:

Final energy model of the Cornerstore



127. SE View of final SketchUp



128. SW View of final SketchUp Model

PHIUS 2015+ CLIMATE SPECIFIC PERFORMANCE REQUIREMENTS

City	Arlington
State	VA
ASHRAE 2013 &	Washington, DC
Global Solar Radiation Location	Washington Natl Airport
Zone	4A
Annual heating demand kBtu/sf·iCFA·yr	4.2
Annual cooling demand kBtu/sf·iCFA·yr	6.4
Peak heating load Btu/sf·iCFA·h	4
Peak cooling load Btu/sf·iCFA·h	4.9
Manual J Peak cooling load Btu/sf·iCFA·h	7
Airtightness requirement	0.6 ACH50

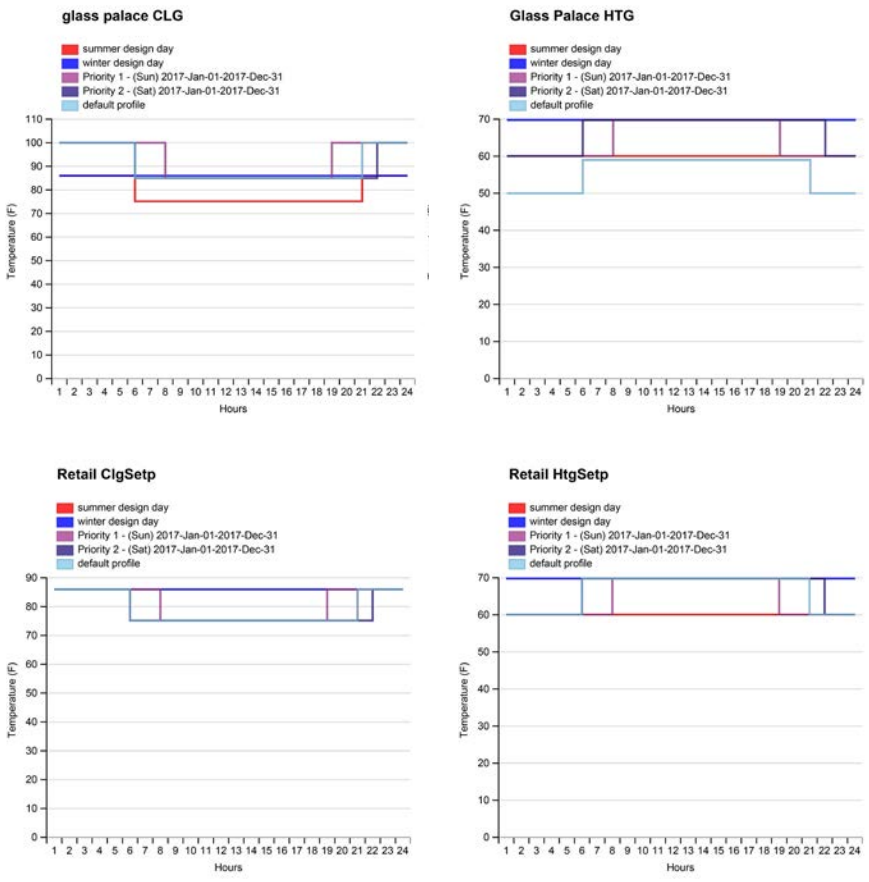
The final Cornerstore energy modeling of Part 3 expands on the modeling done in Part 2. Building 01 with energy model type A and the Best Set construction materials were used. The goal of this energy modeling was to understand the annual heating and cooling demands of the final design and to see whether the building could meet the low energy standards for consumption set by the Passive House Institute of the US (PHI-US) 2015+ program for Climate Zone 4A.

The energy modeling focused on heating and cooling demands because the architectural decisions of the design process had a direct impact on these loads whereas the other quantifiable loads such as the total site and source energy demands of a building include equipment, process, and plug loads which are influenced by other factors of design. To get accurate source energy value requires decisions on what type of energy is used to operate the building such as gas, electricity, or renewable energy. These are decisions that rely on the collaboration of a multi-faceted design team and owner. Lighting, plug, and process loads rely on the integration of design engineers and also includes input from the end user specifically for plug loads. For the purpose of this study, the energy modeling remained focused solely on implications of architectural decisions.

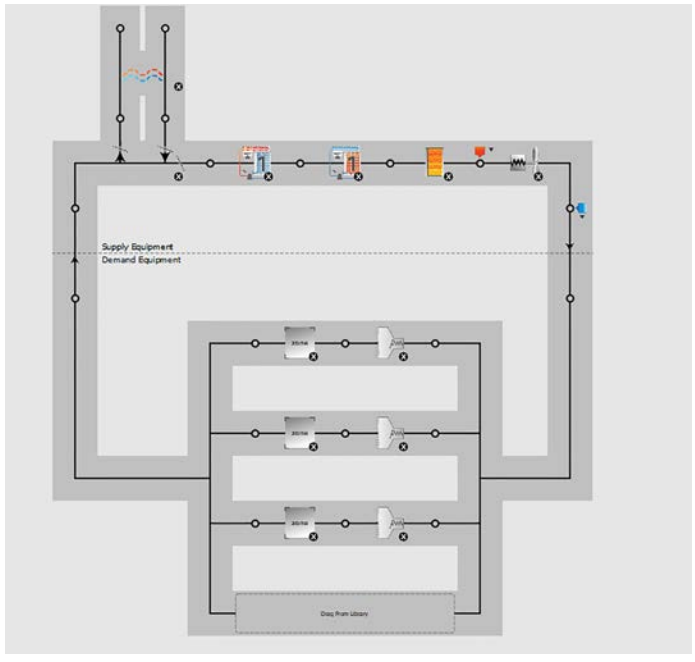
The SketchUp model was updated to reflect the dimensions of the final floor plans, elevations, volume of the Cornerstore building design, and the 03° rotation. Shading devices and the skylights were also added. In the final SketchUp model for OS (as shown to the left), the skylights were constructed as flat rectangular openings on the roof surface plane. This is because Open Studio does not recognize circular openings on a surface. The rectangular skylights in the OS model equal the area of the final skylight designs.

For this final modeling series, the standard Retail building type was still used but modifications to schedules and definitions were added step by step in order to achieve more accurate results.

First, a low energy lighting definition of 0.40 W/ft^2 was used for all lighting loads and remained constant in all simulations of the series. Using a low energy lighting power load reflects what would be used in a high performance/low energy building and since lighting impacts the heating and cooling loads in conditioned spaces, it was important factor to include.



129. Heating and Cooling set point schedules from Open Studio results show the 10° difference between the default temperature set points of the Retail Htg/Clg and the "Glass Palaces" (TZ4 stair/corridor, TZ6 lower level patio) Htg/Clg.



130. The HVAC system diagram from Open Studio is an example of the Packaged Rooftop Heat pump system with a variable speed fan and an energy recovery ventilation heat exchanger at the supply and exhaust air supply used for the two primary HVAC systems that each supply air to three zones.

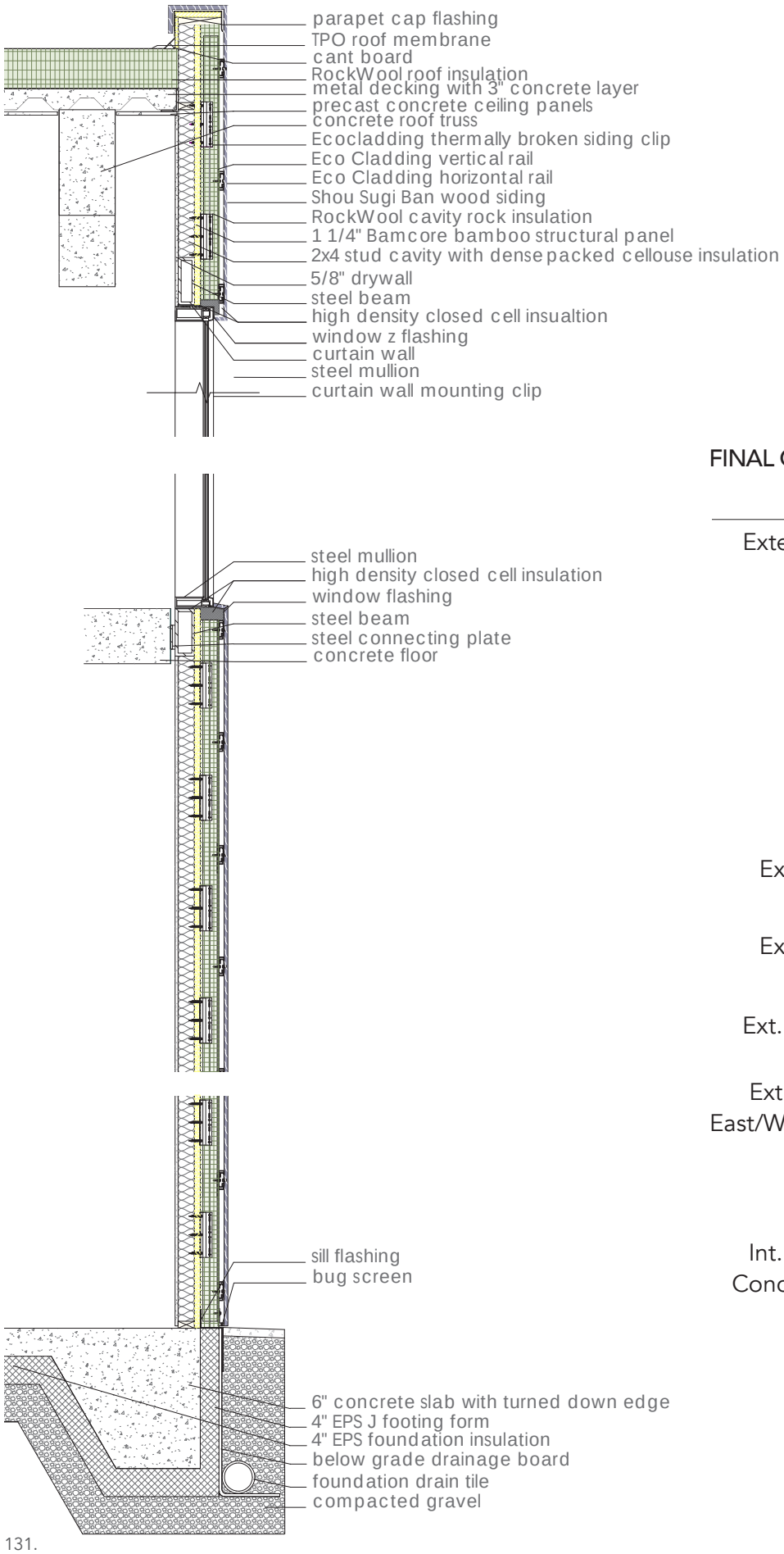
Next, the heating and cooling schedules for the in-between zones, TZ4 Stair/Corridor, and TZ6 Lower Level Patio, were modified. The cooling design temperature of these two zones was changed to 85°F instead of 75°F and the heating design temperature was set to 59° from 69°F allowing these spaces to require less heating and cooling than the core conditioned spaces.

The infiltration rates were modified to reflect an airtight building construction as required by the PHIUS standard of 0.6 ACHp50. The requirement of 0.6 air changes at a pressure of 50 pascals was converted to cubic feet per minute at a natural pressure and the infiltration schedules were modified by thermal zone using the design flow rate calculation method by space in cfm.

Improved window performance factors were added to the windows and curtain walls based on orientation. For northern facing windows, high solar heat gain coefficients (SHGC) and high visual transmittance (VT) were used. For south, east and west facing windows low SHGC and high VT were used. The windows of the concrete walls had average SHGC and VT values.

Finally HVAC systems were introduced to the thermal zones that included energy recovery ventilation (ERV). The systems were developed in Open Studio with the consulting help from Steven Winter Associates, NYC. The eight thermal zones were organized into 4 separate heat pump systems with separate ERV supply and exhaust air. The first HVAC system covered the ground level zones of the convenient store, lobby, and cafe. The second HVAC system covered the lower level gallery, upper level lobby, and upper level gallery. The third HVAC system was for the stair/corridor and the fourth system was for the lower level patio.

As each of these measures were implemented, a new energy model simulation was performed. The results showed that each measure reduced the total heating and cooling loads except for the infiltration rate changes. The most significant changes in heating and cooling loads were a result of adding in HVAC systems with energy recovery ventilation.

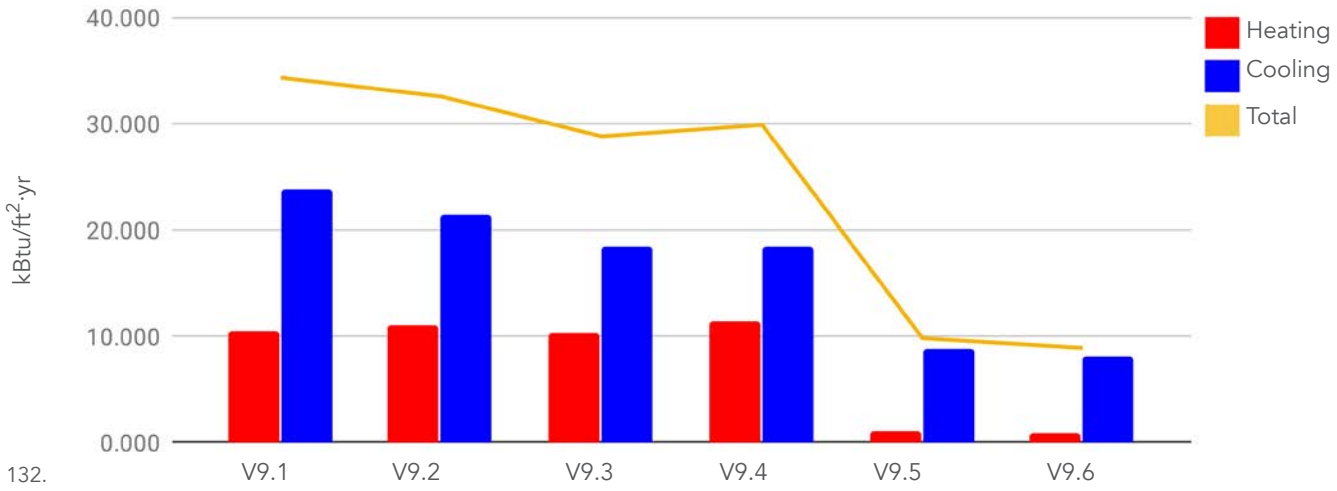


131.

FINAL CONSTRUCTION SET

Assembly	Description	R Value (hr·°F·ft^2/Btu)
Exterior Walls	2x4 stud cavity w/dense pack cellulose 1 1/4" Bamcore wall panel sheathing 4" Roxul cavity rock insulation board Shou Sugi Ban wood siding hung on Eco-cladding thermally broken siding clips	36
Roof	4" concrete metal deck 8" Rockwool Cavity Rock DD EPDM , 45 mil	44
Ext. Ground Wall	Concrete footing 4" EPS insulation in "J form"	25
Ext. Ground Floor	4" concrete slab 4" continuous EPS insulation	25
Ext. Windows North	SHGC 0.53 VT 0.73	10.9
Ext Windows East/West/South	SHGC 0.25 VT 0.73	10.9
Skylights	Kalwall skylights SHGC 0.13, VT 0.10	20
Int. Windows Concrete walls	SHGC 0.37 VT 0.58	10.9

HEATING AND COOLING DEMANDS FOR FINAL ENERGY MODEL SERIES



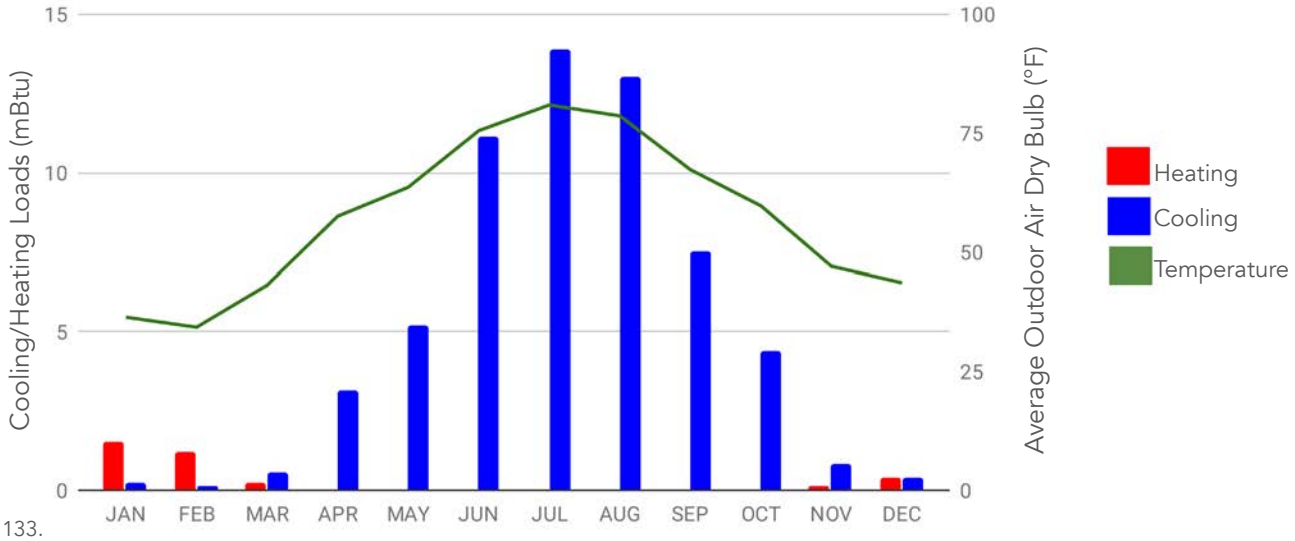
132.

Model Name and Description	Annual HTG/CLG (kBtu/yr)		Area (ft^2)	Total Htg/Clg ($kBtu/ft^2 \cdot yr$)	Total Combined ($kBtu/ft^2 \cdot yr$)
V9.1: updated geometry, reduced lighting load, 03° rotation	HTG	78,928	7462	10.58	34.33
	CLG	177,243		27.53	
V9.2: add shading around stair and patio.	HTG	83,022	7462	11.13	32.56
	CLG	159,964		21.44	
V9.3: modify cooling and heating schedules for TZ4 Stair and TZ6 Patio	HTG	76,663	7462	10.27	28.79
	CLG	138,208		18.52	
V9.4: modify infiltration rates per thermal zone by design flow rate (cfm)	HTG	85,767	7462	11.49	29.88
	CLG	137,224		18.39	
V9.5: Add two primary HVAC Zones with energy recovery ventilation	HTG	7,729	7462	1.04	9.84
	CLG	65,642		8.80	
V9.6: Add two secondary HVAC Zones with energy recovery ventilation	HTG	3,568	7462	0.47	8.92
	CLG	60,543		8.11	

This graph and data table show the annual heating and cooling demands in $kBtu/ft^2 \cdot yr$ for the final Cornerstore energy model as each of the performance measures in Part 3 where implemented. The graph shows incremental reductions in both heating and cooling loads from the first three measures. In V9.4, the change in infiltration rates to meet PHIUS 2015+ standards increased the annual loads slightly but insignificantly. The final two measures had the greatest impact with the introduction of the HVAC systems. In V9.5, two primary HVAC systems with ERV's were added, and in V9.6 the two secondary HVAC systems were added to complete the whole building system. Adding the HVAC systems reduced the annual loads by 70%.

With HVAC + ERV systems, the performance values dropped within range of the passive house standards for annual heating and cooling. The heating load for the final model V9.6 was 0.47 $kBtu/ft^2 \cdot yr$, which is well below the requirement of ≤ 4.2 $kBtu/ft^2 \cdot yr$. The cooling load of V9.6 was 8.11 $kBtu/ft^2 \cdot yr$ which is slightly higher than the requirement of ≤6.4 $kBtu/ft^2 \cdot yr$.

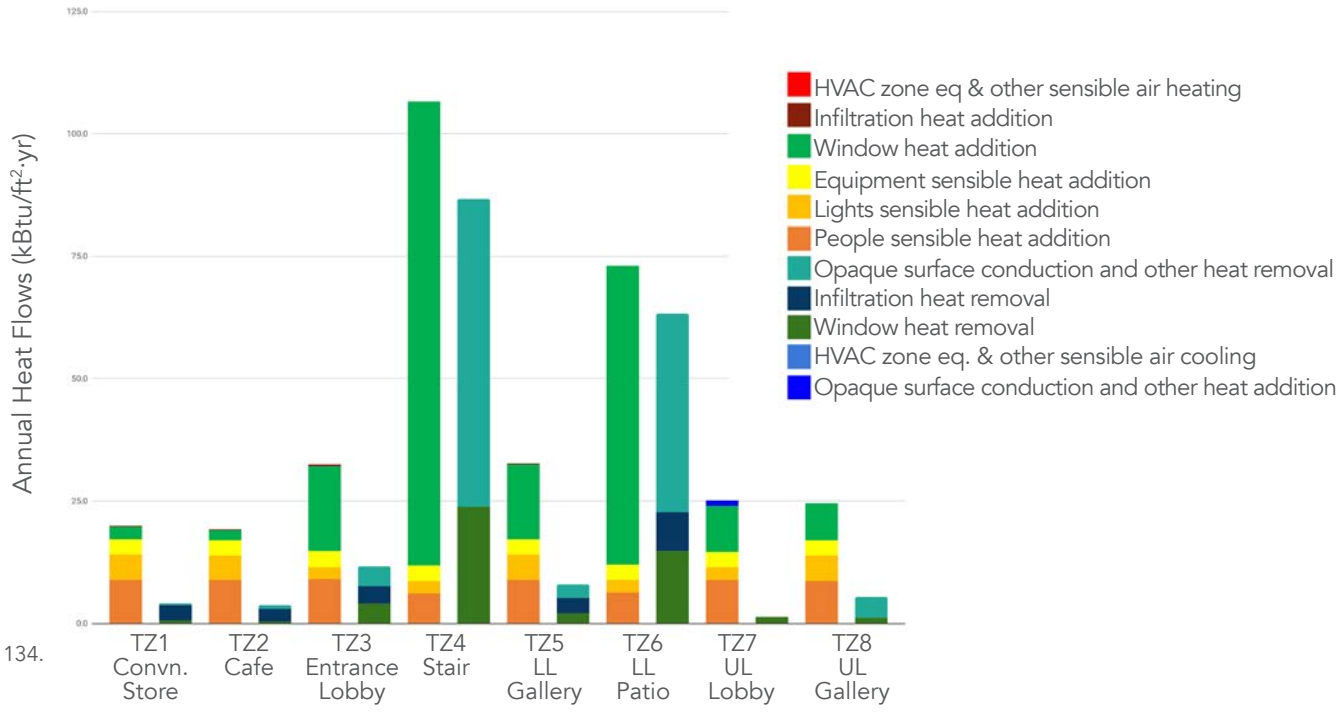
MONTHLY HEATING AND COOLING DEMANDS VS. OUTDOOR TEMPERATURE OF FINAL MODEL



133.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TEMP	36.4	34.3	43.1	57.5	63.6	75.5	80.9	78.6	67.3	59.7	47.0	43.6
CLG	0.24	0.15	0.59	3.14	5.22	11.16	13.87	13.0	7.5	4.4	0.83	0.4
HTG	1.51	1.19	0.25	0.02	0.01	0.0	0.0	0.0	0.01	0.02	0.13	0.42

ANNUAL HEAT FLOWS BY TYPE IN EACH THERMAL ZONE OF FINAL MODEL

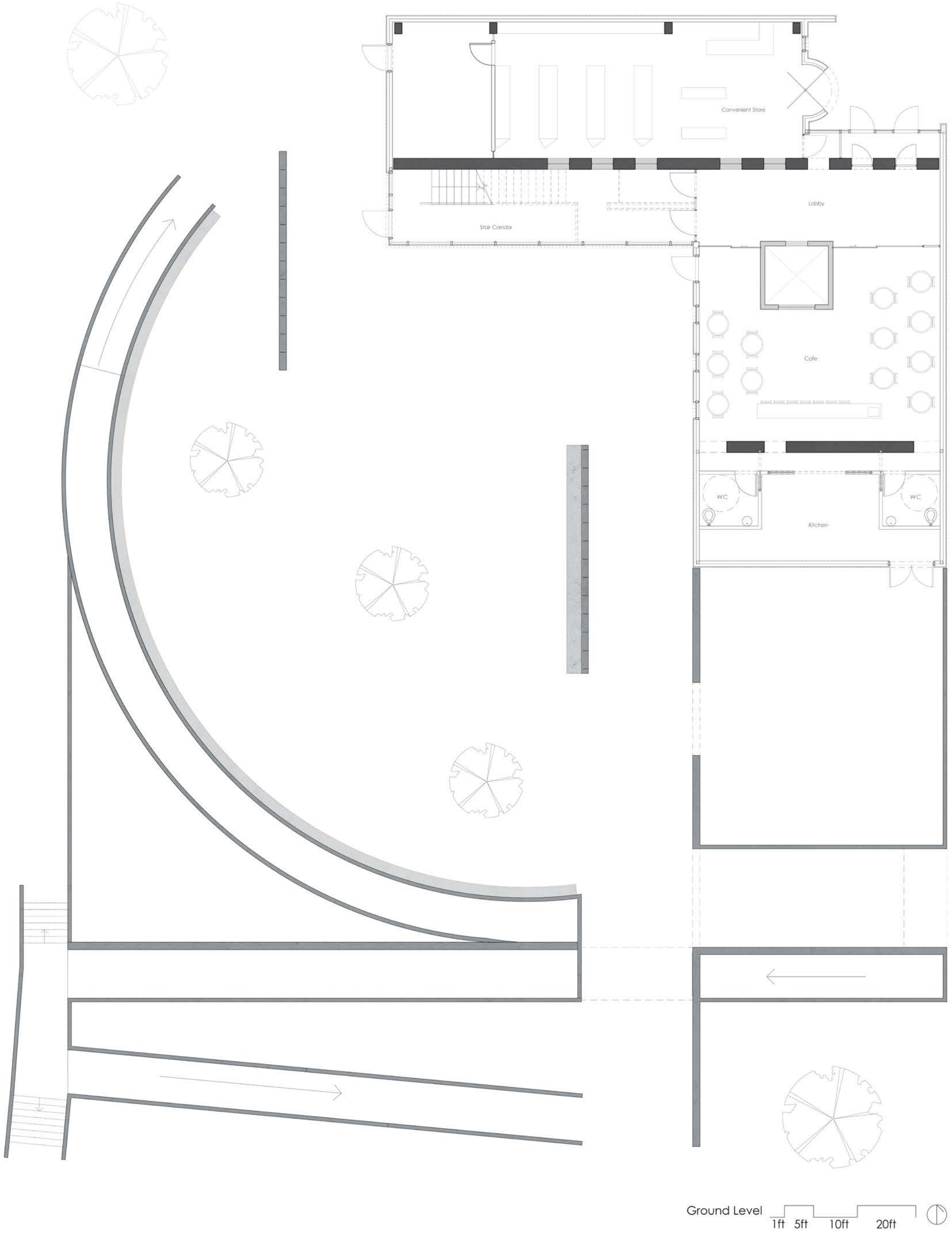


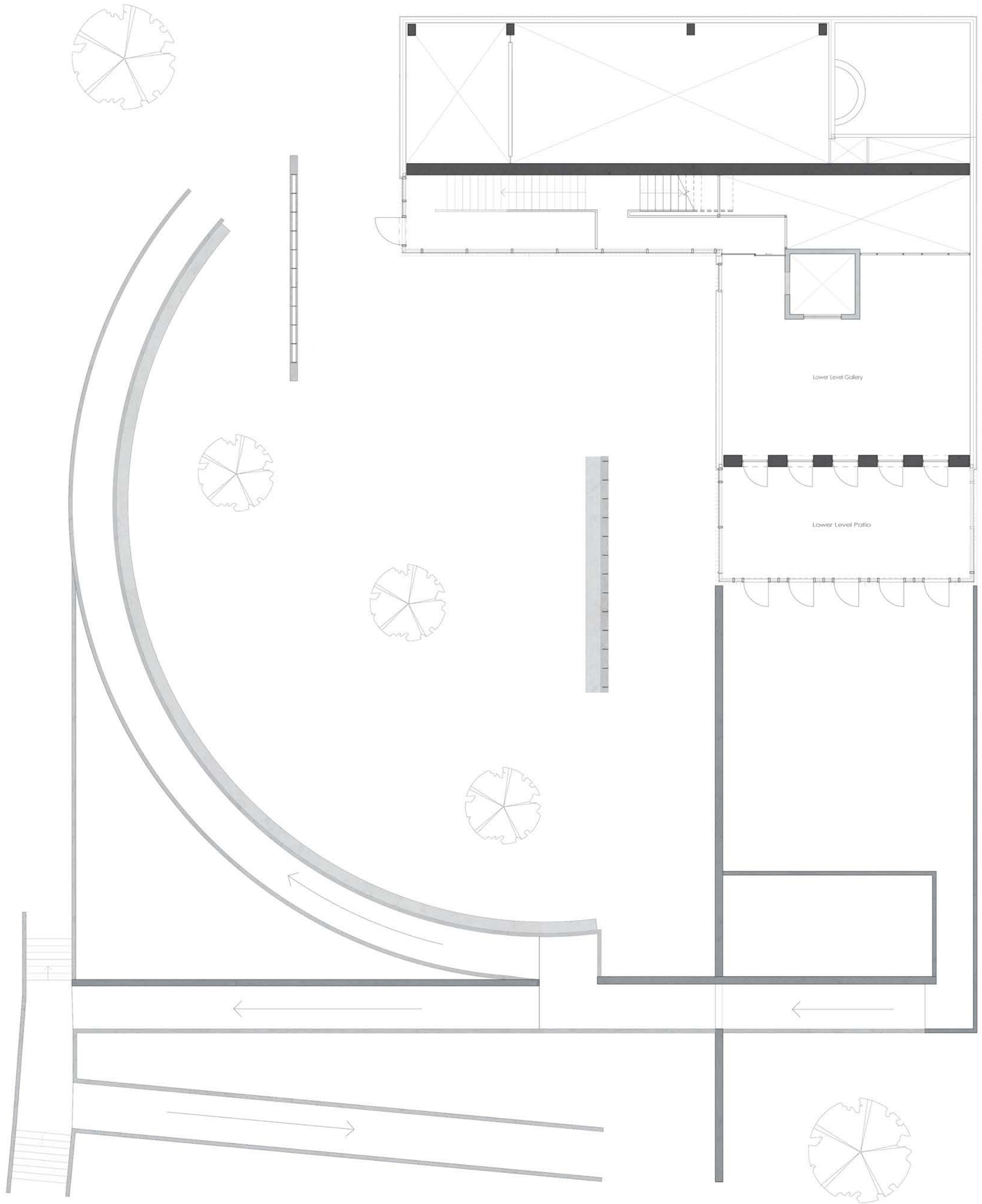
134.

The first graph and data table above show the monthly heating and cooling demands in mBtu against the average monthly temperature of the final Cornerstore energy model, V9.6. The cooling loads are significantly higher compared to the heating loads. The final model includes the TZ4 Stair/Corridor and TZ6 Lower Level Patio and these two zones contribute greatly to the cooling loads. As discussed in Part 2, the cooling loads could be minimized in the winter months by directing waste heat to other adjacent zones. This could also lower the annual cooling demand closer to the PHIUS 2015+ requirement.

The second graph shows the annual heat flow by type for each thermal zone in the final model. This demonstrates that the heat losses and gains of TZ4 Stair/corridor and TZ6 Lower level patio are much greater than any other thermal zones.

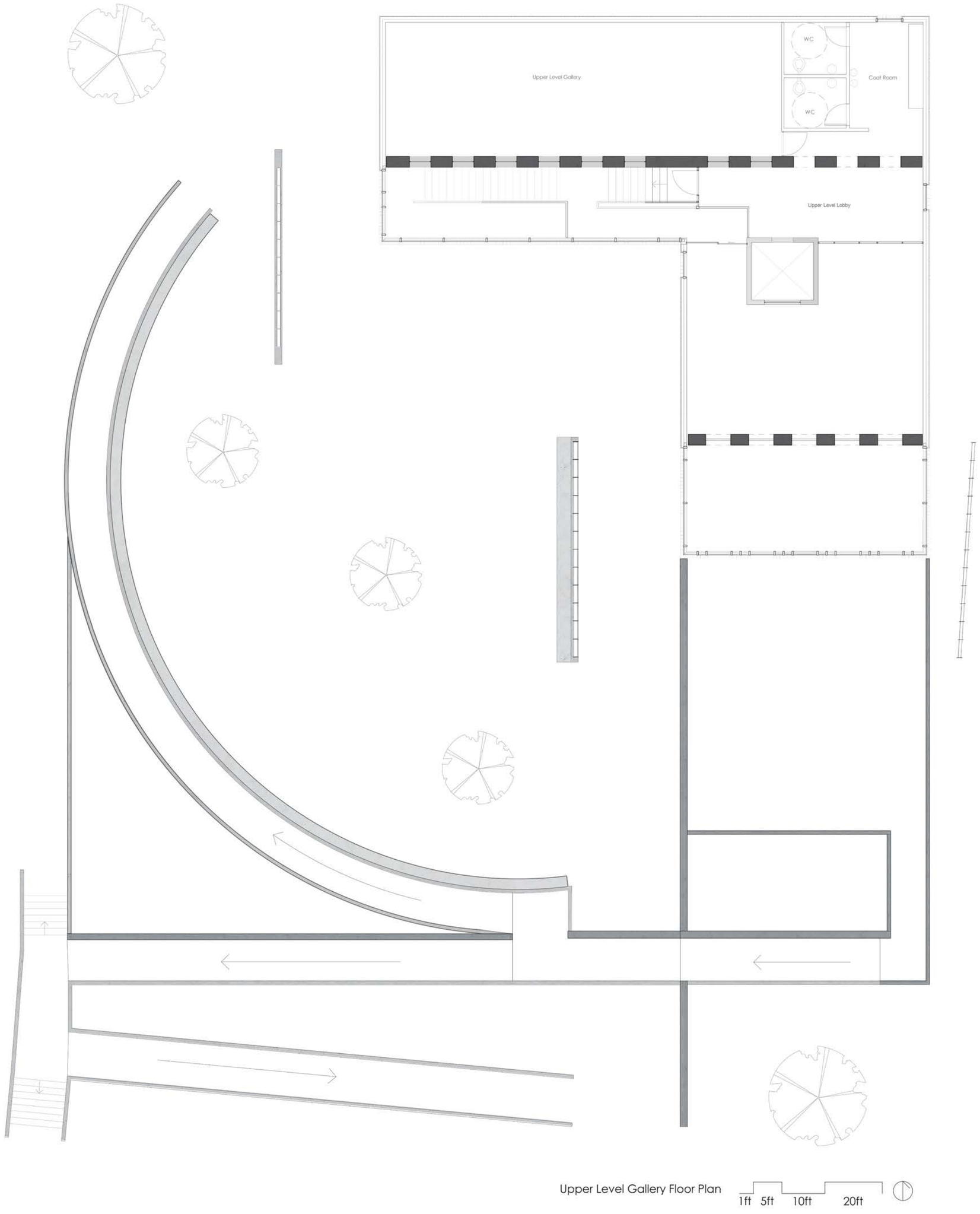
Plan Set


Convenient Store
Stair Corridor
Lobby
Cafe
WC
WC
Kitchen
Ground Level
1ft 5ft 10ft 20ft



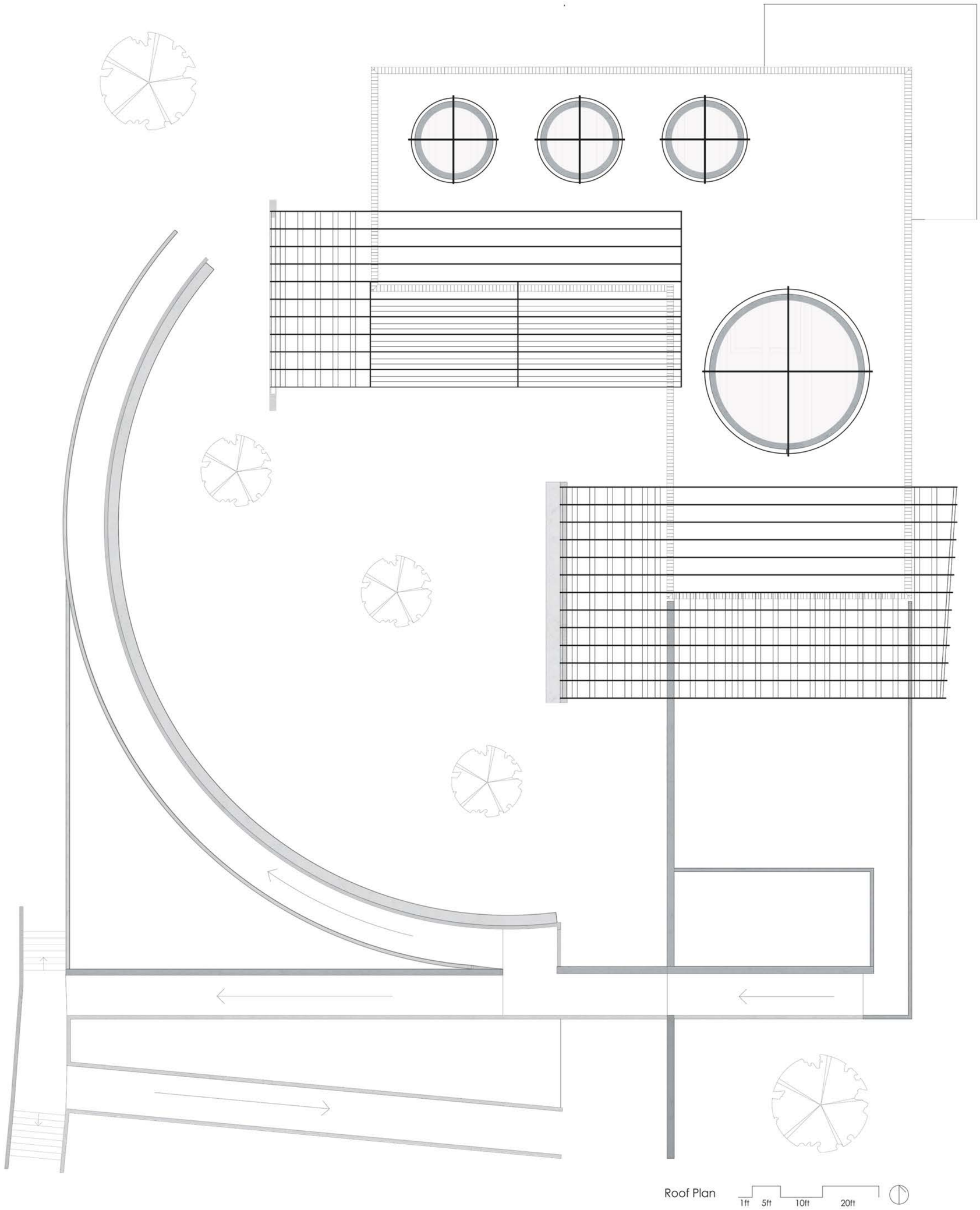
Lower Level Gallery Floor Plan

1ft 5ft 10ft 20ft

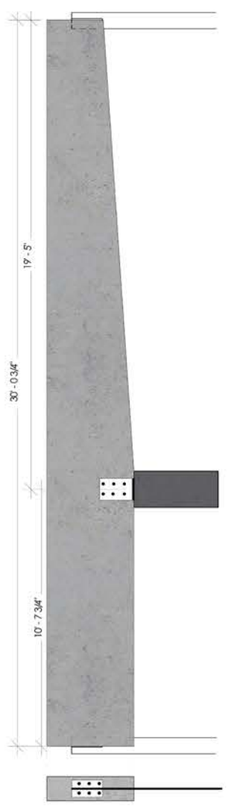


Upper Level Gallery Floor Plan

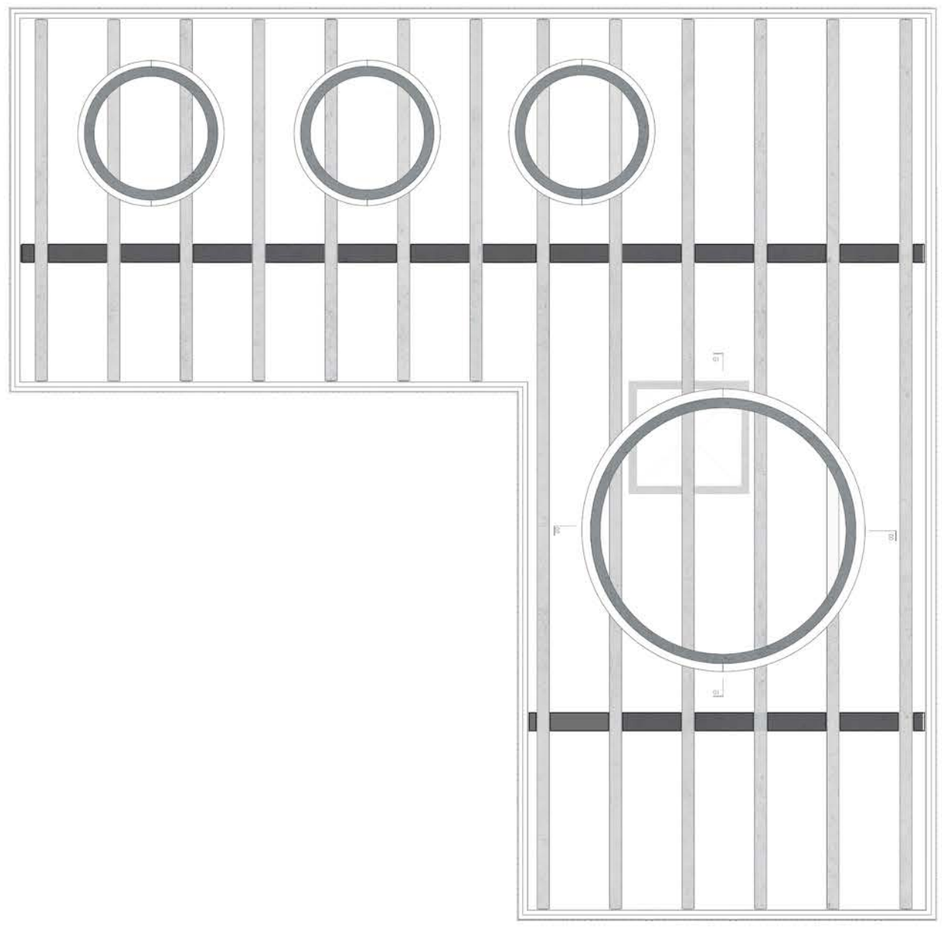
1ft 5ft 10ft 20ft

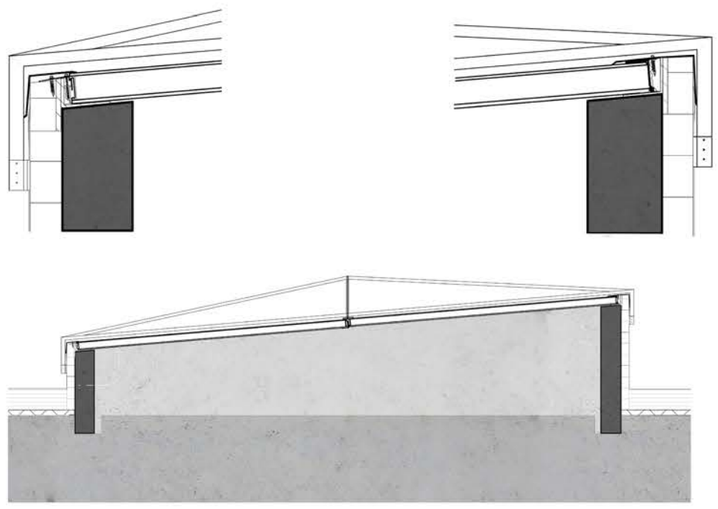

Roof Plan
1ft
5ft
10ft
20ft

Long Concrete Truss

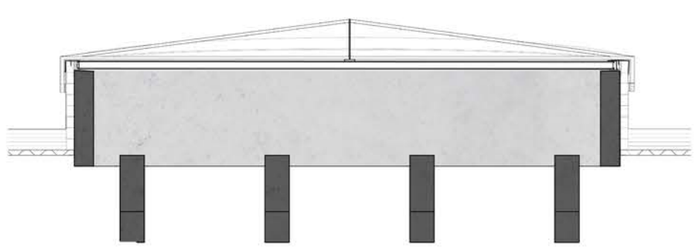


Short Concrete Truss



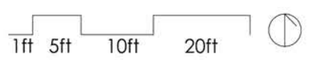


01 Skylight Section



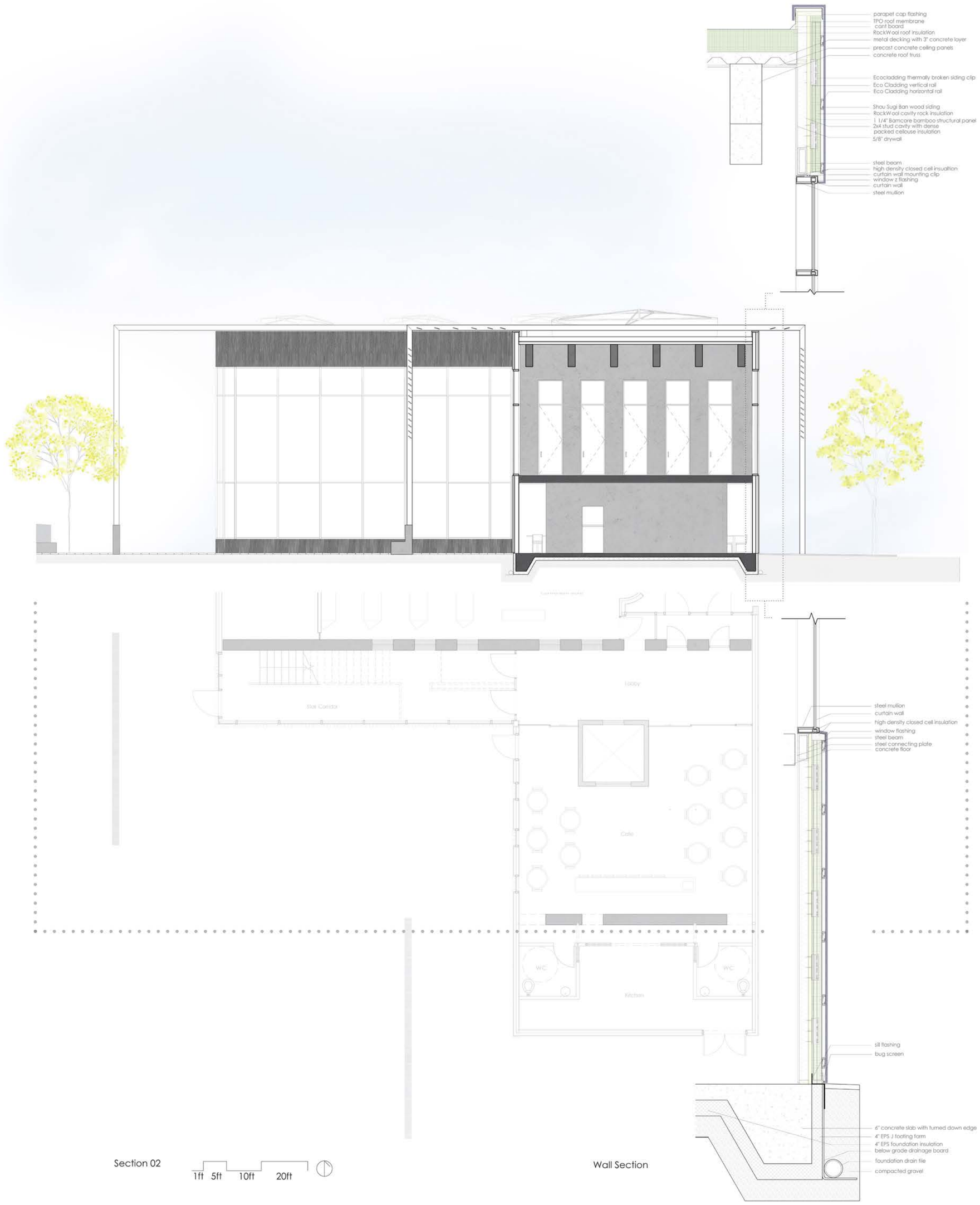
02 Skylight Section

Concrete Roof Truss Plan



Section 01

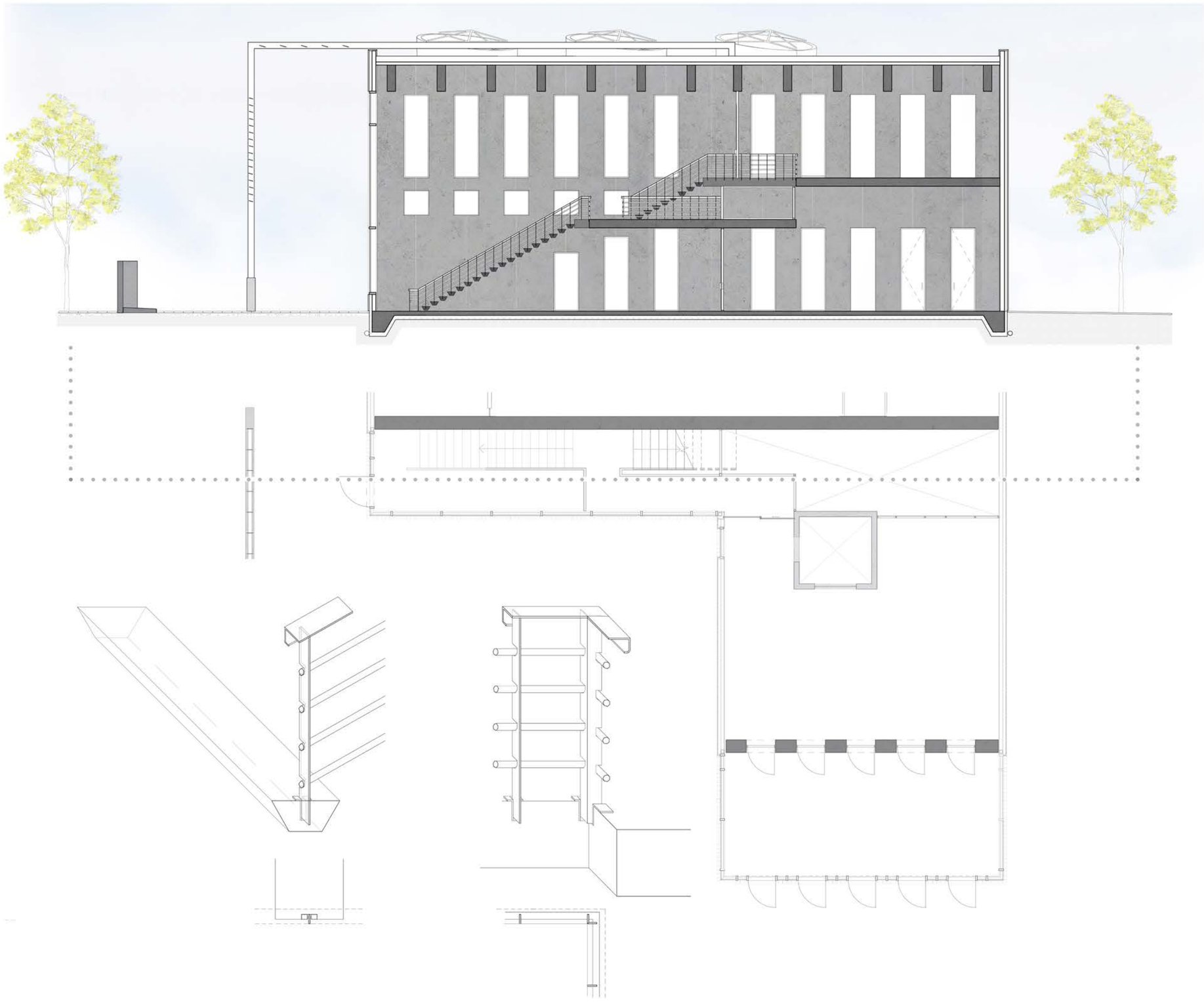
1ft 5ft 10ft 20ft



Section 02

1ft 5ft 10ft 20ft

Wall Section



Section 03 and Stair Details

1ft 5ft 10ft 20ft

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