THE HAEBLER GROUP
GENERAL CONTRACTORS CONSTRUCTION MANAGEMENT DESIGN-BUILD ENGINEERS
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HIGH-VOLUME FLY ASH AS A SUPPLEMENTARY CEMENTING MATERIAL

A CASE STUDY:

ARTHUR ERICKSON DESIGNED

ARTIST LIVE / WORK STUDIOS

1540 WEST 2nd AVENUE

VANCOUVER, BC CANADA

By: Michael Neundorf & Roland Haebler, P. Eng.

The Haebler Group, General Contractor

1. INTRODUCTION

This is a case study about the use of high-volume fly ash concrete in the project Artist Live/Work Studios, located at 1540 West 2nd Avenue in Vancouver, Canada.

The subject development is comprised of high-quality Artist Live/Work Studios, commercial retail space, and a restaurant grouped around a large courtyard. Each of these studios is based on an interlocking unit plan that features a 16-foot high clear space, which is fully glazed and opens onto an exterior deck. The entire development area is about 65,000 square feet.

The structural frame is constructed of cast in place, and post tensioned concrete, which has an exposed sandblasted surface. The finishes are robust: galvanized and stainless steel, steel mesh and concrete. The floors of the studios have radiant heating installed under a polished concrete topping.

The studios are broken into four major, seven-story blocks that are partly interconnected. They take into account the slope of the site and help to define the inner courtyard. A large 65-foot opening separates the street from the inner courtyard. The underside of the opening is curved and also made of exposed concrete.

The following companies are involved in this project:

Owner:	Hillside Developments Ltd.
Architect:	Nick Milkovich Architects, Arthur Erickson Design Consultant
Structural Engineer:	Fast & Epp Structural Engineers
General Contractor:	The Haebler Group
Concrete Placer:	Newway Forming Ltd.
Material Engineer:	Amec Earth & Environmental Ltd.
Ready-Mix supplier:	Ocean Construction Supplies Ltd.

2. OBJECTIVE OF THIS REPORT

A lot of research on high-volume fly ash concrete has been done in the last few years. This new type of concrete was developed at CANMET / NRCan, Ottawa, Canada, and is slowly getting acceptance worldwide. There are two main reasons for this :

2.1 Technical aspect

The durability of concrete has become a serious problem and widespread premature deterioration, e.g. of bridges and parking garages, is now well-recognized. Estimates for repair and rehabilitation of existing concrete infrastructure run into the billions of dollars. (P.K. Mehta, "Durability - Critical Issues for the Future", *Concrete International* 7 / 97)

The lack of durability originates from many factors. However, it is generally accepted that the primary causes of deterioration of concrete are the corrosion of reinforcing steel, frost action, alkali-aggregate expansion and sulfate attack. This is a result of cracking, which commonly occurs during the early age and is caused by thermal stresses induced by heat of hydration such as drying shrinkage and creep strains.

The use of fly ash in concrete reduces the amount of water required for a given slump. This results in achieving the desired concrete strength with less drying shrinkage and plastic cracking. Also it leads to less heat of hydration, less weak zones due to water bleeding to the surface.

Another effect is the slow pozzolanic reaction of silica. Fly ash is comprised of approximately 70-80% silica. The silica in the pozzolans reacts gradually with the Calcium Hydroxide salts to form Calcium Silicate Hydrate, which is the predominate binder. Calcium Hydroxide is a byproduct of the main reaction of Portland cement.

As a result of the above mentioned properties, fly ash increases strength and impermeability, and finally the durability of the concrete.

2.2 Environmental aspect

Cement manufacturing results in a high amount of CO_2 emissions, which strongly contributes to the greenhouse effect and to global warming. Each tonne of Portland cement produced results in approximately one tonne of CO_2 released. Making one tonne of cement also consumes 4-5 GJ of energy. It is expected that the demands for Portland cement in the world will double in about 25 years. (P.K. Mehta, Ibidim)

On the other hand, fly ash is a waste product of coal-fired power plants. 75 to 80% of the fly ash produced goes to landfills.

Therefore, by using higher volumes of fly-ash in concrete as a replacement for cement, there is an opportunity to reduce greenhouse gas emissions, alleviate a fly ash disposal problem, save natural resources, and produce a high quality product.

Utilizing high-volume fly ash concrete is a relatively new practice for the Canadian construction industry. The construction industry often reacts cautiously to new technologies. The architects and structural engineers, as well as the concrete placers and finishers, have to get accustomed to the differences this type of concrete imposes on them, before they will condone its use. The difference in this material and the experience with it in this project are discussed in greater detail below.

Like all investigations, we need to know more about practical uses of high-volume fly ash concrete. This will help us to overcome some barriers and to become more familiar with the product. Describing both the technical experiences gained and economic issues resulting, this report should contribute to increase the knowledge and understanding of this new technology.

3. DETAILED REPORT

3.1 Reasons for application

For the 1540 West 2nd project, almost every part of the vertical components (walls, columns, curbs) and also the soffit of the ceilings, was designed to be made of exposed concrete. It was the desire of the owner and the architect to get uniform, first class architectural concrete. To achieve a warmer tone, they contemplated using a colored concrete.

However, the initial price of the project was over budget. Cost savings were pursued in order to cut cost and meet the owner's expectations. The Haebler Group suggested the use of high-volume fly ash concrete. Haebler had used this product in a recently completed project, the Liu Centre for the Study of Global Issues at UBC. With this project, the company had developed some good experience using high-volume fly ash concrete, especially in producing a smooth and attractive architectural concrete.

After visiting the Liu Center with the owner and the architect, Haebler cast several sample walls in the parkade, using different mixtures of high-volume fly ash concrete, and other architectural concrete mixes that they had previous success with. After review of approximately 11 samples it was agreed to use the high-volume fly ash mix. The primarily reason for this selection was that this mix best met the requirements in respect of colour and surface finishes.

At the outset of the project, it should be noted that the decision to use high-volume fly ash concrete was chosen as a matter of aesthetics, and not because of its durability or environmental benefits. This technology was used to obtain a lighter colour, and a higher quality surface finish to the concrete.

Applying it for that reason, we discovered an additional and important benefit of high-volume fly ash concrete that has not been mentioned in the literature before. All participants are very satisfied with the outcome of the concrete. Fewer bug holes are found, the surface is smoother and the walls and columns look lighter and more homogeneous.

3.2 Quantity and mix design

At this point we need to have a critical review of the definition of high-volume fly ash concrete. We have to distinguish between mixtures in which part of the cement is replaced with fly ash, and standard mixtures. To identify an environmental benefit, it would be more precise to talk about the amount of cement replaced with fly ash, compared to a mixture with 15% - 20% fly ash or none at all.

Table 1: Mix design of Case Study compared to Standard 30- and 40-MPa-mixtures (quantity per cubic metre)

	Case Study	**Standard 30 MPa**	**Standard 40 MPa**
Cement Fly ash Subtotal Cementitious Material	195 kg 195 kg 390	240 kg 65 kg 305	310 kg 80 kg 390
Sand Stone, 20 mm Water Admixture	760 kg 1080 kg 140 L 1/2 L (Regular and High range water reducing admixture)	--	--
Air content	3 ± 1 %	< 4 %	< 4 %
Placement slump	110 mm	80 mm	80 mm

In this project the structural engineer specified that a concrete be used for the exterior walls that had a minimum 28 day strength of 30 Mpa and a F-2 exposure clarification. Therefore our Case Study mix had to meet these structural criteria. Looking at Table 1,

we note that there was still 195 kg/m^3 of cement in the mixture, and compared to the originally specified 30 MPa concrete, the replacement of cement was only 19% (240-195 / 240). While reducing the amount of cement, the absolute volume of cementitious materials (cement + fly ash) exceeded that of the cementitious material in the specified 30 MPa mix (390 compared to 305). This increase in paste volume produced a “creamy” concrete with improved plasticity and better cohesiveness, which was responsible for the enhanced quality of exposed concrete.
Concrete placement ranged in sizes from 3 to 45 m^3 daily with a total estimated at 1,000 m^3.

3.3 Weather conditions

We started with the casting of samples in the parkade on May 16, 2000. The construction phase is expected to be finished on November 30, 2000. Temperature varied from 8^o C to 26^o C during the pours. Within this range we did not notice any significant variations on the setting process.

However, it should be noted that we have no experience applying high-volume fly ash concrete either in cold temperatures, nor for large suspended slabs.

3.4 Workability

The small glassy spherical particles of the fly ash improve the plasticity of the resulting fresh concrete. While using almost the same amount of superplasticizer, compared to mixtures not containing fly ash, it allows a lower water content in the concrete.

We noticed an enhanced pumpability of the concrete. However, placing was somewhat more difficult. According to the superintendent, Tom Dimitroff, the material tends to “roll” and has a “fuzzy” feel when trowelled. According to Ocean Construction Supplies Ltd. this may be related to the finishers working on the slab before it has adequately set.

The fresh concrete is more sticky, which requires a longer and more intensive vibrating. Because the surface is drying faster, more care is needed to keep the concrete wet during the first days, in order to get the required strength. Altogether it resulted in about 20% of extended time for placing and curing of the concrete.

Other than noted above, use of this concrete was similar to traditional concrete mixes. We used the same type of forms and the same type of release agent, that we would use in similar projects. There were also no problems gaining sufficient early strength for stripping. Usually after 24 hours the forms of vertical units were stripped.
A notable improvement is the surface of the concrete. The surface is more even and smooth, and there are less air bubbles. Depending on the care taken during forming and placing, there could be less labour required for patching and cement finishing. This could reduce the increased time and cost associated with placing and curing.

3.5 Strength

As mentioned before, the mix design was created more for architectural than structural demands. Initially there were some concerns about gaining sufficient early strength by using a high-volume fly ash concrete.

However, the test results of the Liu Centre, showed an enormous increase of strength between the 28^{th} and the 90^{th} day. In discussion with Fast & Epp, it was agreed that during the construction phase the structure is not experiencing actual design live loads. Thus it is not necessary to achieve the specified 28-days strengths, at 28 days, provided that these specified strengths are reached well before the structure experiences the design loads. Consequently the structural engineers, Fast and Epp, agreed to extend their requirement for 30 MPa-strength to 56 days.

It should again be emphasized that the composition of the concrete was not primarily focused on structural demands, but on architectural ones. However, the resulting strength was more similar to a 35 or 40 MPa concrete (See table 2). Interestingly it should be noted that the amount of cementitious material is similar to that of a normal 40 Mpa mix (See Table 1), but using 37% less cement (310-195 / 310).

Table 2: Results of compressive strength

1 day	5.0 MPa
2 day	13.5 MPa
7 days:	27.4 MPa
28 days:	41.5 MPa
56 days	44.7 MPa

Nevertheless, actual test results indicate that strengths above 30 MPa were obtained in 28 days. In fact, many tests indicated strengths exceeding 40 Mpa in 28 days. These test results show an astonishing early-age strength was achieved. Because of that, there are no differences in stripping time, nor any impacts on the schedule. (See Table 2)

3.6 Cost factors

Labour and material costs, except the cost for the concrete itself, are very comparable to standard solutions. The equipment used is the same. More labour is needed for placing and curing, but less for patching and sacking if proper precautions are taken.

Using high-volume fly ash concrete for vertical elements had no remarkable impact on the schedule..

Compared to a standard mixture with a specified strength of 30 MPa at 28 days, the cost of the Case Study-mix concrete was approximately 10 to 15% greater. However, the high-volume fly ash concrete gained a strength of more than 40 Mpa after 28 days. Compared to a 40-Mpa standard mix, the price would be approximately 10% lower.

The reason for the higher price of the Case Study mix compared to standard 30 Mpa concrete is due to the fact that the Case Study mix uses 28% more cementious material. (390 compared to 305 – see Table 1).

Without a requirement for exposed concrete, it may be easier to obtain the same or even a better price for a high-volume fly ash concrete, compared to a traditional concrete mixture.

In case of exposed concrete, a certain amount of cementitious materials is required to gain a high quality finish. If those conditions are adjusted to properly meet the structural demands, it should also be possible to achieve a reasonable price.

4. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER PROJECTS

One of the challenges for the construction industry in the future will be to use new, high-performance materials and technologies, produced at reasonable cost and with the lowest possible environmental impact.

There is a tendency to look principally at the project's cost, which leads to higher speeds of construction. In the future, we should have a more holistic view of all other costs, including life cycle, ecological and social costs. The use of high-volume fly ash concrete could enhance the structure's service life by improving durability.

The mixture used in this project gained sufficient early strength. There was no impact on the schedule in terms of curing and stripping time.

It is important to start the consideration of using a high-volume fly ash concrete at an early stage; if possible, before the structural design is finalized.

Designing structures on the basis of 56 or 90 day strengths, instead of 28 day strength, is possible for many types of projects. This would assist designers in accepting high-volume fly ash concrete as an alternative to possibly conventional mixes, and possibly result in lower costs.

To gain the most efficient results, high-volume fly ash concrete should be judged on 56- or 90-day strength. On this basis, the concrete is achieving higher strength which allows a more cost-effective mix design.

Having gained experience in two recent projects, The Haebler Group is a strong advocate for high-volume fly ash concrete.

APPENDIX A : FEEDBACK FROM THE MAIN PLAYERS

Owner: Bahman Sanii of Hillside Developments Ltd.

Hillside Developments Ltd. is very satisfied with the quality of the exposed concrete. The two main reasons for applying:

1. Costs were cut, compared to a coloured concrete.
2. The concrete fits to the demands of colour and texture.

Although, to consider the use of high-volume fly ash concrete in future projects, a financial advantage is necessary. The market will not bear extra charge for an eco-image of the concrete right now.

Architect: Alain Prince of Nick Milkovich Architects

Nick Milkovich Architects got a good impression about the appearance of the exposed concrete units. Environmental benefits are an important side effect. Considering both, they are interested in using high-volume fly ash concrete in further projects.

Structural Engineers: Paul Fast of Fast & Epp

As structural engineers, Fast & Epp has been involved in technical studies and building projects that have assessed and incorporated the use of higher than normal volumes of fly ash in cast-in-place and precast, pre-stressed concrete components. They have found that increased fly ash content generally results in stronger, more durable concrete with an aesthetically pleasing light brown hue. Caution should however be exercised when placing high-volume fly ash concrete in cold temperatures as the lower temperatures tend to retard curing time.

General Contractor: Roland Haebler P. Eng, of Haebler Group

We are very pleased with the results obtained using the high-volume fly ash concrete mixes. The surface is very dense, and the colour for gray type concrete is much warmer when compared to conventional mixes. The extra work required is well worth the effort if the building design and weather conditions warrant its consideration. We would welcome opportunities to use this mix again.

APPENDIX B: COMPRESSSIVE STRENGTH TESTS – AMEC

2227 Douglas Road, Burnaby, BC V5C 5A9
Tel: (604) 294-3811 Fax: (604) 294-4664

CONCRETE TEST REPORT

CERTIFIED CONCRETE TESTING LABORATORY IN ACCORADANCE WITH STD A283.2-94

PROJECT NO. VA-04759
CLIENT Hillside Developments
C.C. Material Division
Haebler Construction Ltd. FAX:874-0841
Fast & Epp

Vancouver

TO Haebler Construction Ltd.
FAX:874-0841
46 E. 3rd. Ave.
Vancouver, BC

ATTN: Roland Haebler

RECEIVED
NOV 7 2000
HAEBLER/H.C.M.

PROJECT 1540 West 2nd Avenue

SET NO. 75 NO. OF SPECIMENS 14 DATE RECEIVED 2000.Nov.03 DATE CAST 2000.Nov.02

SPCM NO.	SPECIMEN TYPE	CURE CONDN	DATE TESTED	AGE AT TEST (DAYS)	AVERAGE DIAMETER (mm) OR SIDE (mm x mm)	AVERAGE LENGTH OR SPAN (mm)	MAXIMUM LOAD (kN)	COMPRESSIVE OR FLEXURAL STRENGTH (MPa)	Average	FAILURE TYPE
A	Cylinder	Lab	Nov.09	7	101.6	203.2				
B	Cylinder	Lab	Nov.30	28	101.6	203.2				
C	Cylinder	Lab	Nov.30	28	101.6	203.2				
D	Cylinder	Lab	Dec.28	56	101.6	203.2				
E	Cylinder	Field	Nov.03	1	101.6	203.2	44	5.4		
F	Cylinder	Field	Nov.03	1	101.6	203.2	44	5.4		
G	Cylinder	Field	Nov.03	1	101.6	203.2	48	5.9	5.6	
H	Cylinder	Field	Nov.04	2	101.6	203.2	84	10.4		
I	Cylinder	Field	Nov.04	2	101.6	203.2	84	10.4		
J	Cylinder	Field	Nov.04	2	101.6	203.2	90	11.1	10.6	

SPECIFIED STRENGTH 30 MPa @ 28 DAYS
CEMENT CONTENT kg/m³ TYPE 10
POZZOLAN CONTENT kg/m³ TYPE FA
MAXIMUM SIZE AGGREGATE 10 mm
BATCH TIME 14:16
ADMIXTURES
SPN 1L/m3

CONCRETE TEMP. 17 °C AIR TEMP. 13 °C
SLUMP 130 mm SPEC. 70 ± 20
AIR 1.5 % SPEC. 3.0 ± 1.0
PLASTIC DENSITY kg/m³
HARDENED DENSITY kg/m³
CAST TIME 16:00
CAST BY AEE AS
CURING CONDITIONS
INITIAL CURING TEMP MAXIMUM 18 °C MINIMUM 15 °C

TREND GRAPH

MOULD TYPE PLASTIC

LOCATION

SUPPLIER Ocean Construction
MIX NO. HC1
TRUCK NO. 801 TICKET NO. 1-584776
LOAD VOL. 12 m³ CUM. VOL. 12 m³
WATER ADDED AUTH. BY
Page 1 of 2 2000.Nov.06

COMMENTS
1st 3 breaks @ 24hrs - 16:00
2nd 3 breaks @ 48hrs - 16:00
3rd 3 breaks @ 72hrs - 16:00

AGRA Earth & Environmental PER.

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of test results is provided only on written request.

NOV-07-00 TUE 08:40 AGRA E&E FAX NO. 6042944664 P. 02

2227 Douglas Road, Burnaby, BC V5C 5A9
Tel: (604) 294-3811 Fax: (604) 294-4664

CONCRETE TEST REPORT

CERTIFIED CONCRETE TESTING LABORATORY IN ACCORADANCE WITH STD.A283.2-94

PROJECT NO. VA-04759

TO Haebler Construction Ltd.
FAX:874-0841
46 E. 3rd. Ave.
Vancouver, BC

ATTN: Roland Haebler

RECEIVED
NOV 7, 2000
HAEBLER/H.C.M.

CLIENT Hillside Developments
C.C. Material Division
Haebler Construction Ltd. FAX:874-0841
Fast & Epp

PROJECT 1540 West 2nd Avenue Vancouver

SET NO. 75 NO. OF SPECIMENS 14 DATE RECEIVED 2000.Nov.03 DATE CAST 2000.Nov.02

SPCM NO.	SPECIMEN TYPE	CURE CONDN	DATE TESTED	AGE AT TEST (DAYS)	AVERAGE DIAMETER (mm) OR SIDE (mm x mm)	AVERAGE LENGTH OR SPAN (mm)	MAXIMUM LOAD (kN)	COMPRESSIVE OR FLEXURAL STRENGTH (MPa)	Average	FAILURE TYPE
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L	Cylinder	Field	Nov.05	3	101.6	203.2	114	14.1		
M	Cylinder	Field	Nov.05	3	101.6	203.2	112	13.8	13.8	
N	Cylinder	Field			101.6	203.2				

SPECIFIED STRENGTH 30 MPa @ 28 DAYS

CEMENT CONTENT kg/m³ TYPE 10

POZZOLAN CONTENT kg/m³ TYPE FA

MAXIMUM SIZE AGGREGATE 10 mm

BATCH TIME 14:16

ADMIXTURES

SPN 1L/m3

SUPPLIER Ocean Construction

MIX NO. HC1

TRUCK NO. 801 TICKET NO. 1-584776

LOAD VOL. 12 m³ CUM. VOL. 12 m³

WATER ADDED I AUTH. BY

Page 1 of 2 2000.Nov.06

CONCRETE TEMP. 17 °C AIR TEMP. 13 °C

SLUMP 130 mm SPEC. 70 ± 20

AIR 1.5 % SPEC. 3.0 ± 1.0

PLASTIC DENSITY kg/m³

HARDENED DENSITY kg/m³

CAST TIME 16:00

CAST BY AEE AS

CURING CONDITIONS

INITIAL CURING TEMP.MAXIMUM 18 °C MINIMUM 15 °C

TREND GRAPH

MOULD TYPE PLASTIC

LOCATION

COMMENTS
1st 3 breaks @ 24hrs - 16:00
2nd 3 breaks @ 48hrs - 16:00
3rd 3 breaks @ 72hrs - 16:00

AGRA Earth & Environmental PER. ________

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of test results is provided only on written request.

FROM :KONICA FAX TO : 604 436 6707 2000,10-19 01:12PM #767 P.02/02

amec

CERTIFIED CONCRETE TESTING LABORATORY IN ACCORDANCE WITH STD A283.2-94

2227 Douglas Road, Burnaby, BC V5C 5A9
Tel: (604) 294-3811 Fax: (604) 294-4664

CONCRETE TEST REPORT

TO Haebler Construction Ltd.
FAX:874-0841
46 E. 3rd. Ave.
Vancouver, BC

ATTN: Roland Haebler

PROJECT NO. VA-04759
CLIENT Hillside Developments
C.C. Material Division
Haebler Construction Ltd. FAX:874-0841
Fast & Epp

RECEIVED
OCT 19 2000
HAEBLER/H.C.M.

PROJECT 1540 West 2nd Avenue — Vancouver

SET NO 71 NO. OF SPECIMENS 6 DATE RECEIVED 2000.Oct 12 DATE CAST 2000.Oct.11

SPCM NO	SPECIMEN TYPE	CURE CONDN	DATE TESTED	AGE AT TEST (DAYS)	AVERAGE DIAMETER (mm) OR SIDE (mm x mm)	AVERAGE LENGTH OR SPAN (mm)	MAXIMUM LOAD (kN)	COMPRESSIVE OR FLEXURAL STRENGTH (MPa) Average	FAILURE TYPE
A	Cylinder	Lab	Oct.18	7	101.6	203.2	206	25.4	
B	Cylinder	Lab	Nov.08	28	101.6	203.2			
C	Cylinder	Lab	Nov.08	28	101.6	203.2			
D	Cylinder	Lab	Dec.06	56	101.6	203.2			
E	Cylinder	Field	Oct.12	1	101.6	203.2	35	4.3	
F	Cylinder	Field	Oct.13	2	101.6	203.2	132	16.3	

SPECIFIED STRENGTH 30 MPa @ 28 DAYS
CEMENT CONTENT kg/m³ TYPE 10
POZZOLAN CONTENT kg/m³ TYPE FA
MAXIMUM SIZE AGGREGATE 10 mm
BATCH TIME 15.18
ADMIXTURES
Superplast 0.5L/m3

SUPPLIER Ocean Construction
MIX NO. HC1
TRUCK NO 803 TICKET NO. 1682487
LOAD VOL 12.2 m³ CUM VOL 12.2 m³
WATER ADDED I AUTH BY
Page 1 of 1 2000.Oct 19

CONCRETE TEMP. 19 °C AIR TEMP 16 °C
SLUMP 110 mm SPEC 70 ± 20
AIR 1.2 % SPEC. 3.0 ± 1.0
PLASTIC DENSITY kg/m³
HARDENED DENSITY kg/m³
CAST TIME 16:55
CAST BY AEE TY
CURING CONDITIONS
INITIAL CURING TEMP:MAXIMUM 21 °C MINIMUM 15 °C
LOCATION
Parapet Wall: West side

COMMENTS

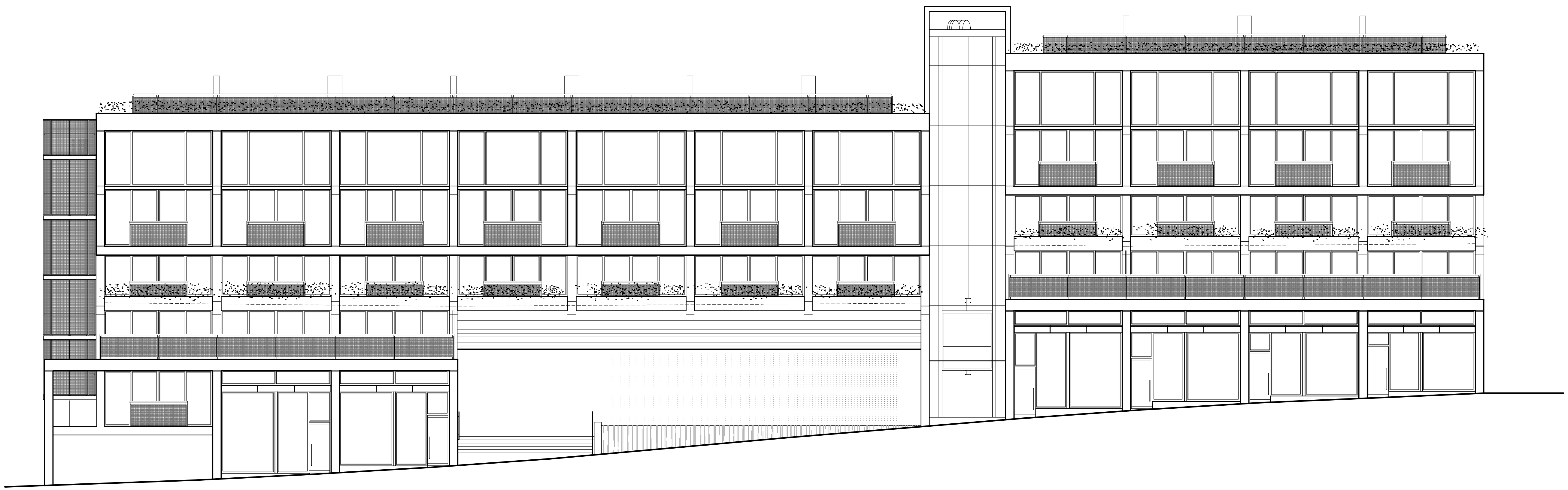
AGRA Earth & Environmental PER [signature]

TREND GRAPH

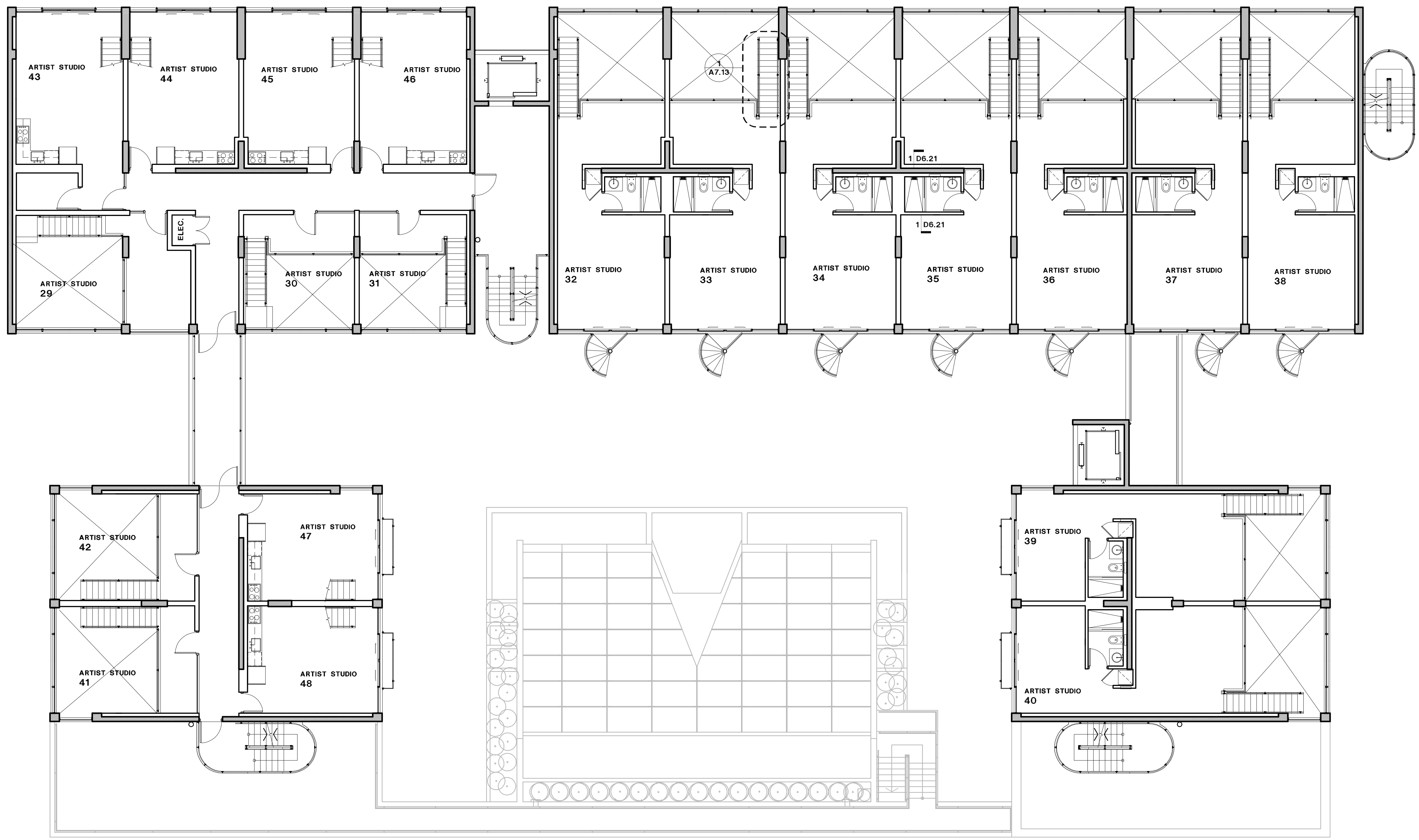
MOULD TYPE PLASTIC

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of test results is provided only on written request

APPENDIX C : ARCHITECT'S DRAWINGS



NORTH ELEVATION - BLOCKS A & B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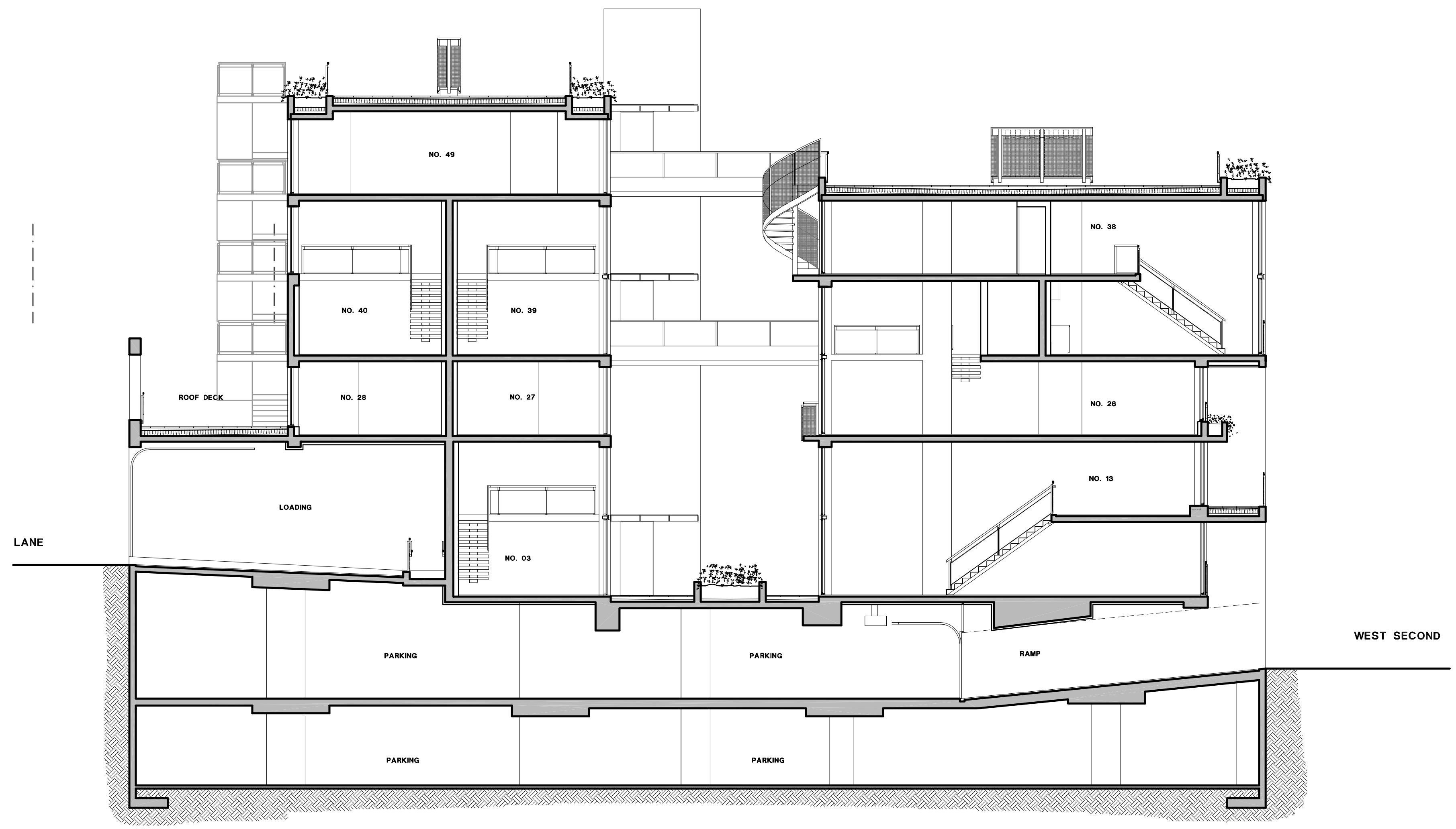
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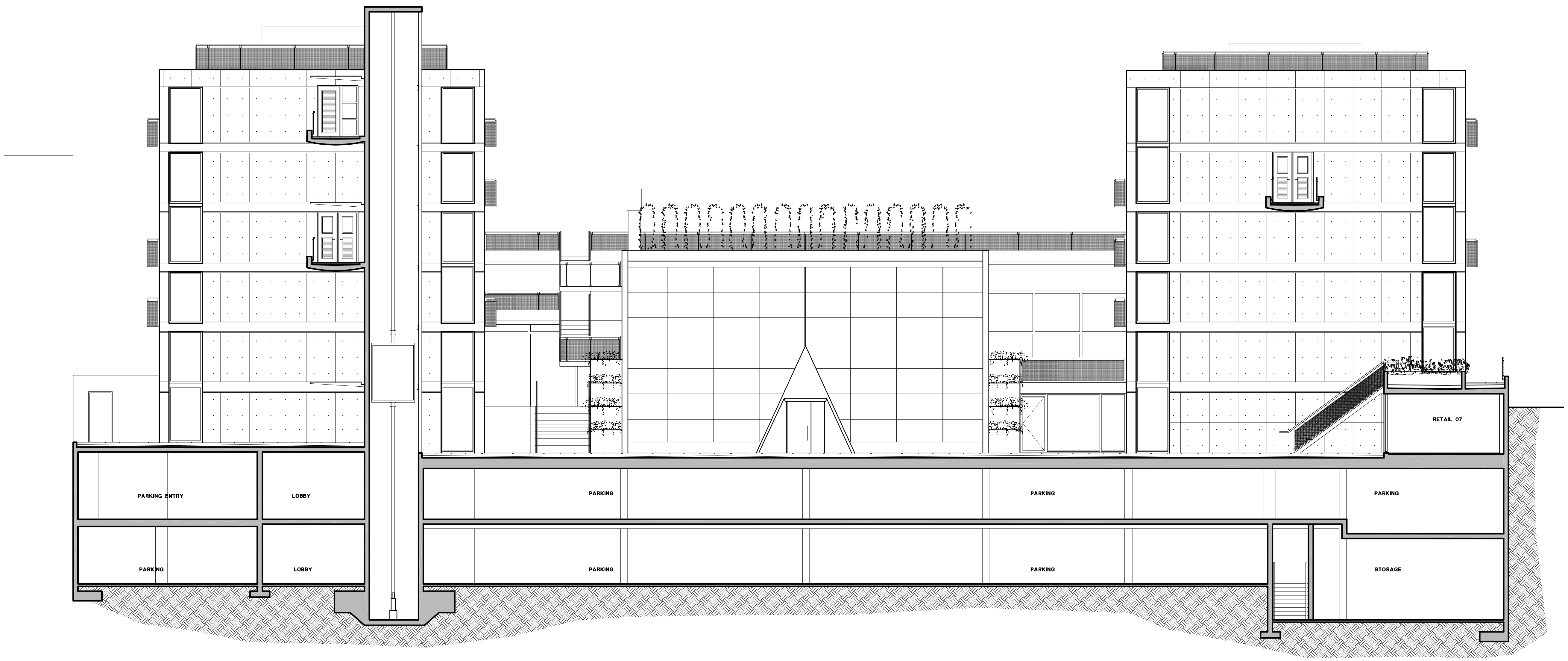
PARKING
RAMP
PARKING
PARKING



SECTION F
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