AN INTEGRATED BUILDING SYSTEM

by

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DEAR DEAN ANDERSON:

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARCHITECTURE, I HEREBY SUBMIT THIS THESIS ENTITLED, "AN INTEGRATED BUILDING SYSTEM" DEVELOPED FOR USE IN A UNIVERSITY LABORATORY AND RESEARCH COMPLEX.

RESPECTFULLY,

RONALD M. MARGOLIS

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ABSTRACT

AN INTEGRATED BUILDING SYSTEM DEVELOPED FOR USE IN A UNIVERSITY LABORATORY AND RESEARCH CENTER

BY RONALD MICHAEL MARGOLIS

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE ON JUNE 17, 1968 IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARCHITECTURE.

THE INTENT OF THIS THESIS WAS THE DEVELOPMENT OF A SYSTEM FOR BUILDING THAT REFLECTS THE INTEGRATION OF THE STRUCTURAL, MECHANICAL, ENVIRONMENTAL CONTROL, SPATIAL, GROWTH, AND ADAPTATION CONSIDERATIONS OF A BUILDING INTO A UNIFIED AND ORDERLY METHOD OF MEETING OUR BUILDING NEEDS.

THE SYSTEM THAT EVOLVED WAS A PRECAST REINFORCED CONCRETE STRUCTURE SPANNING 60'-0" FROM COLUMN TO COLUMN IN BOTH DIRECTIONS. IT USES TO ADVANTAGE THE RELATIVE SIMPLICITY OF ONE-WAY CONSTRUCTION WITH THE MORE EFFICIENT STRUCTURAL ASPECTS OF A TWO-WAY SYSTEM. THE 3'-9" STRUCTURAL DEPTH ALLOWS FOR OPTIMUM MECHANICAL SERVICE PENETRATION IN TWO DIRECTIONS IN CONJUNCTION WITH MAXIMUM STRUCTURAL EFFICIENCY.

THE VERTICAL PENETRATION ELEMENTS SUCH AS STAIRS, ELEVATORS, AND MECHANICAL AND PLUMBING EQUIPMENT OCCUR IN ACCORDANCE WITH THE STRUCTURAL MODULE AS IS DEEMED NECESSARY BY PLANNING OR CODE.

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INTRODUCTION

"THE BEST KNOWN AND PROBABLY THE LEAST THOUGHT ABOUT GENERATOR OF BUILDING SYSTEMS IS... EVOLUTION. IN OTHER WORDS, THE ECONOMIC FORCES AT WORK IN THE WORLD ... GENERATE BUILDING SYSTEMS."[1] THE CONCEPT OF A BUILDING SYSTEM IS NOT NEW OR REVOLUTIONARY. THE IGLOO IS A BUILDING SYSTEM AS IS THE TYPICAL WOOD FRAME HOUSE. EACH IS ADAPTED TO THE CONDITIONS UNDER WHICH IT IS USED. EVOLUTION WILL UNDOUBTEDLY CHANGE BOTH JUST AS IT HAS OUR NEEDS AND REQUIREMENTS. THIS CHANGE IS ESPECIALLY APPARENT IN THE EDUCATION AND HOUSING AREAS OF BUILDING. IN ORDER TO PROVIDE OUR GROWING POPULATION WITH SATISFACTORY SOLUTIONS TO OUR BUILDING PROBLEMS WE MUST DEVELOP NEW METHODS OF CONSTRUCTION THAT WILL REFLECT THESE NEEDS.

"A BUILDING SYSTEM IS A MEANS TO AN END. IT IS A FORM OF ORGANIZATION FOR THE PROCESS OF CONSTRUCTION. THE PURPOSE OF DEALING WITH CONSTRUCTION AS AN INDUSTRIALIZED SYSTEM IS TO ACHIEVE ECONOMY BY REDUCING THE TIME OF CONSTRUCTION, I.E., BY INCREASING THE RATE OF CONSTRUCTION. BUILDING SYSTEMS PERMIT A

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[1]Royal Institute of British Architects, The Industrialization of Building. (April, 1965), p. 7.

MUCH GREATER MECHANIZATION OF THE CONSTRUCTION PROCESS, GREATER INVESTMENT IN EQUIPMENT USED IN PRODUCTION, AND A HIGHER QUALITY OF THE END PRODUCT. THE ECONOMIC IMPLICATIONS OF THE QUALITY OF CONSTRUCTION ARE GREAT AS THEY AFFECT MAINTENANCE, COST OF SERVICING, AND THE CONSUMPTION OF ENERGY OF THE BUILDING SYSTEM."[2]

THE BUILDING SYSTEM CAN BE USED AS A DESIGN TOOL TO ACHIEVE A SOLUTION TO THE PHYSICAL PROBLEMS OF THE ENVIRONMENT. RESPONSIBILITY FALLS UPON THE ARCHITECT, ENGINEER, AND BUILDER TO CONSOLIDATE THEIR EFFORTS TO MAKE A FEASIBLE METHOD OF BUILDING A REALITY. NOT UNTIL THIS UNION IS ACHIEVED CAN THE FULL POTENTIAL OF A BUILDING SYSTEM BE REALIZED.

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[2] Moshe Safdie, "Anatomy of a System;" <u>RIBA Journal</u>, November 1967, p. 489.

DEFINITION

THE TERM SYSTEM CAN BE APPLIED TO ALMOST ANYTHING AND EVERYTHING. IN HIS BOOK, A METHODOLOGY FOR SYSTEMS ENGINEERING, ARTHUR HALL, A SYSTEMS EXPERT AT BELL LABS, DESCRIBES A SYSTEM AS ANY SET OF OBJECTS WITH RELATIONSHIP BETWEEN THE OBJECTS AND BETWEEN THEIR ATTRIBUTES; THUS, SYSTEMS CAN CONSIST OF ATOMS, STARS, SWITCHES, SPRINGS, WIRES, BONES, NEURONS, GENES, MATHEMATICAL VARIABLES, EQUATIONS, LAWS, OR PROCESSES ... ISOLATED OBJECTS OR A PIECEMEAL SERIES OF EVENTS AS INTERCONNECTED AND MUTUALLY DEPENDENT.

CHRISTOPHER ALEXANDER DESCRIBES A SYSTEM'S RELATIONSHIP TO BUILDING AS "A KIT OF PARTS AND A BOOK OF RULES." IT SHOULD PROVIDE A RATIONAL METHOD OF PROCEDURE. IN OTHER WORDS, "THE APPLICATION OF MODERN MANAGEMENT TECHNIQUES TO COORDINATE DESIGN, MANUFACTURING, SITE OPERATIONS, AND OVERALL FINANCIAL AND MANAGERIAL ADMINISTRATION INTO A DISCIPLINED METHOD OF BUILDING."[3] THE BUILDING SYSTEM SHOULD REPRESENT AN ATTITUDE TOWARD BUILDING... "THE ORGANIZATION OF BUILDING INDUSTRIALLY BY APPLYING THE BEST METHODS AND TECHNIQUES TO THE INTEGRATED PROCESS

[4]Royal Institute of British Architects; The Industrialization of Building. (April, 1965), p. 7.

OF DEMAND, DESIGN, MANUFACTURE AND CONSTRUCTION."[4]

A BUILDING SYSTEM, THEN, IS MORE THAN ITS PHYSICAL COMPOSITION. IT REFLECTS A PROCEDURE THAT IS ITSELF A CLEAR RATIONAL SYSTEM.

OBJECTIVES

FEW INSTITUTIONS REFLECT THE INCREASING NEED FOR FLEXIBILITY AS DOES THE UNIVERSITY. THE LABORATORY IN PARTICULAR IS A GOOD INDEX OF THIS CHANGE. EQUIPMENT, TECHNIQUES, AND SPATIAL NEEDS ARE CONSTANTLY BEING MODIFIED. IN ORDER TO KEEP PACE WITH THESE DEVELOPMENTS WE MUST INITIATE A BUILDING SYSTEM THAT IS ABLE TO ANTICIPATE AND ADAPT TO THE UNFORESEEN DEMANDS OF FUTURE REQUIREMENTS. CERTAIN GOALS AND LIMITATIONS ARE SET FORWARD TO MEET THIS CHALLENGE.

1. REINFORCED CONCRETE IS TO BE USED AS THE BUILDING MATERIAL.
2. IT IS NECESSARY THAT AN INTEGRATION OF STRUCTURE, MECHANICAL, LIGHTING, DIMENSIONS, SPATIAL CONDITIONS, AND GROWTH POSSIBILITIES FORM A UNIFIED STATEMENT THAT WILL ADAPT TO A VARIETY OF USES.
3. THE DIMENSIONS MUST BE SUCH THAT THEY WILL PROVIDE A NUMBER OF SPATIAL AND PLANNING COMBINATIONS.
4. THE STRUCTURAL SYSTEM DEVELOPED MUST PROVIDE A BALANCE BETWEEN THE NECESSITIES OF INTEGRATION AND A MAXIMUM OF STRUCTURAL EFFICIENCY.
5. SHIPPING REGULATIONS ARE TO BE CONSIDERED AS A

LIMITATION BOTH ECONOMICALLY AND IN ALLOWABLE DIMENSIONS OF MEMBERS.

THE DEVELOPMENT OF A UNIVERSITY LABORATORY-RESEARCH COMPLEX WILL OFFER A WORTHY CHALLENGE TO THE DEVELOPMENT OF A BUILDING SYSTEM CAPABLE OF MEETING THE OUTLINED OBJECTIVES. FLEXIBILITY AND INTEGRITY IN A BUILDING OF THIS NATURE IS THE VERY ESSENCE OF ITS CONTINUED ACCEPTANCE AS A SUITABLE SPACE FOR PERFORMING ITS VITAL OPERATIONS.

ACCEPTING THE PRESENT LIMITATIONS AND ANTICIPATED DEVELOPMENTS OF TECHNOLOGY, A SOLUTION IS PROPOSED.

BUILDING TYPE

THE KITCHEN OF THE ALCHEMIST IN THE MIDDLE AGES AND THE RESEARCH INSTITUTIONS OF THE TWENTIETH CENTURY ARE MILESTONES IN THE DEVELOPMENT OF THE MODERN LABORATORY. ANCIENT TIMES IN SPITE OF THEIR CONCENTRATION ON MATERIAL PHILOSOPHY DID NOT KNOW THE LABORATORY AS SUCH.[5] A LABORATORY IN THE PRESENT MEANING OF THE WORD PROBABLY MADE ITS FIRST APPEARANCE IN SWEDEN IN 1686. NEW TECHNIQUES, APPARATUS AND EQUIPMENT TOGETHER WITH AN INCREASE IN SCIENTIFIC KNOWLEDGE BEGAN TO TRANSFORM THE APPEARANCE OF THE LABORATORY.

THE DESIGN OF THE DIFFERENT TYPES OF LABORATORIES DEPENDS ON THE TYPE OF WORK TO BE CARRIED OUT, WHETHER THEY ARE REQUIRED FOR TEACHING, DEVELOPMENT OR PRODUCTION CONTROL. IT IS NO LONGER FEASIBLE TO DESIGN A LABORATORY SPACE, BUT WE MUST DESIGN FOR IT. CERTAIN ELEMENTS APPEAR IN EVERY LAB, BUT A MAXIMUM OF FLEXIBILITY IS REQUIRED TO KEEP THE BUILDING FROM BECOMING OBSOLETE WITHIN A SHORT TIME AFTER ITS COMPLETION.

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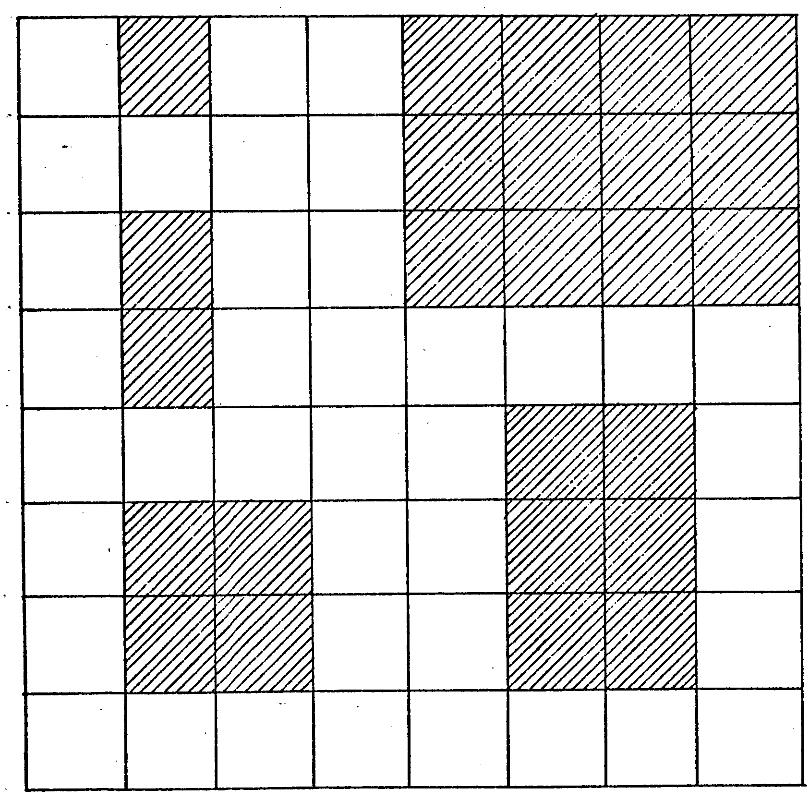
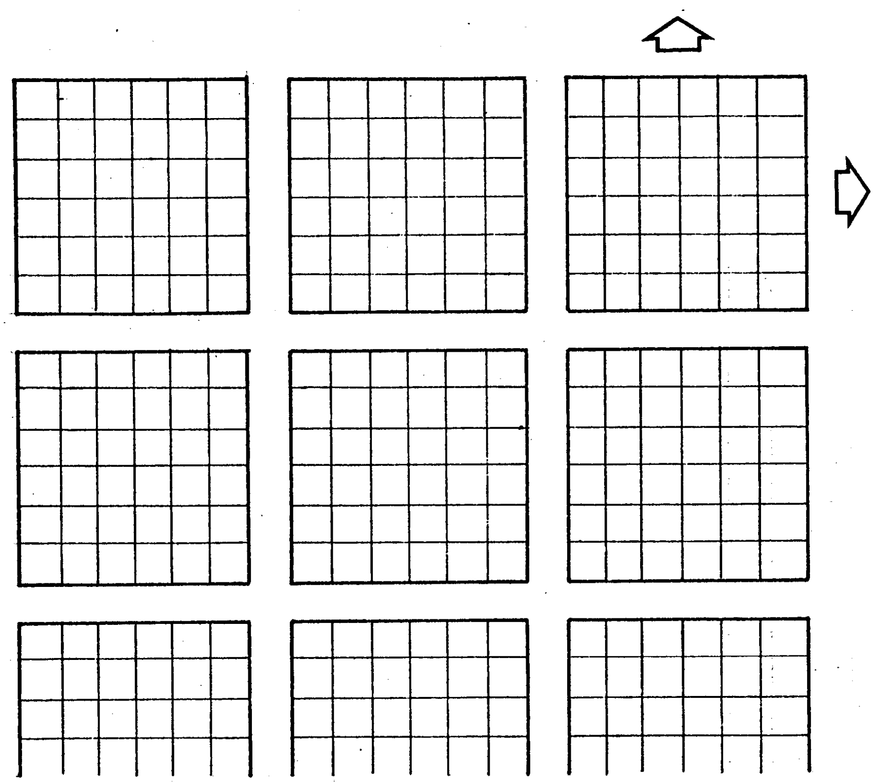
[5]Werner Schramm, Chemistry and Biology Laboratories (Frankfurt: Pergamon Press, 1965), p. 1.

IN AN EFFORT TO KEEP COSTS DOWN IN BOTH CONSTRUCTION AND FURNISHING, MOST LABORATORIES ARE ARRANGED SO THAT A DEFINITE UNIT OF LABORATORY OR OFFICE SPACE REPEATS ITSELF THROUGHOUT THE ENTIRE BUILDING. THE SMALLEST OF SUCH UNITS WILL BE DEFINED AS THE PLANNING MODULE. IF THE FLOOR PLANS ARE BASED UPON A SUITABLE MODULE (10' TO 12'), FLEXIBILITY IN ROOM SIZE IS EASILY POSSIBLE. IT IS NECESSARY THEN ONLY TO PARTITION SPACES AS THE PROGRAM REQUIRES. IF THE TYPE OR SIZE OF A SPACE CHANGES, SO CAN THE PARTITIONS.



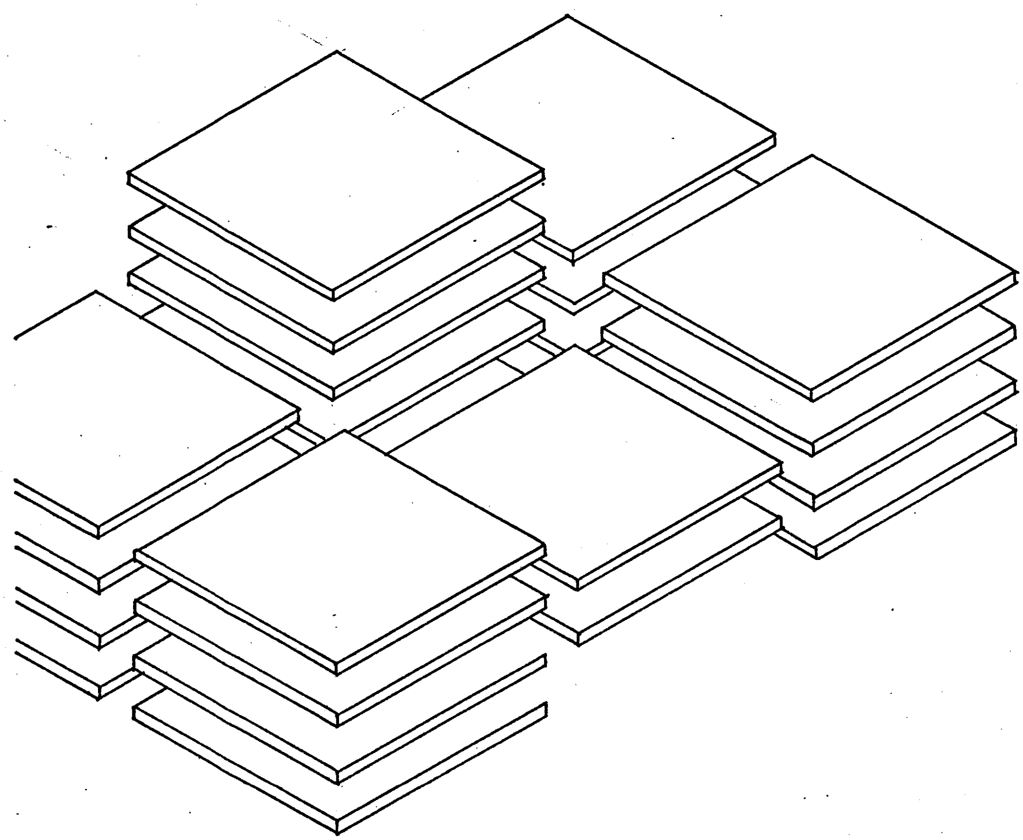
MODULE COMPOSITION

UPON INVESTIGATING VARIOUS EXISTING AND PROPOSED BUILDINGS OF THIS NATURE IT WAS FOUND THAT A 10 X 10 UNIT OF BUILDING WAS NOT SUITABLE. AFTER INSTALLATION OF THE NECESSARY EQUIPMENT THE SPACE BECAME TO SMALL FOR A ONE MAN LABORATORY. A 12 X 12 MODULE WAS THEN DECIDED ON AS THE SMALLEST UNIT OF PLANNING. ALL SPACES THEN BECOME SOME MULTIPLE (OR PARTIAL MULTIPLE AS DESIRED) OF THIS UNIT. FIVE UNITS BY FIVE UNITS FORM A STRUCTURAL BAY WHICH BECOMES STRUCTURALLY INDEPENDENT FROM ITS NEIGHBORS. GROWTH PATTERNS CAN OCCUR IN TWO DIRECTIONS AT 90° TO EACH OTHER.



GROWTH PATTERN

THIS STRUCTURAL DISCONTINUITY ALSO HAS THE ADVANTAGE OF INDEPENDENT GROWTH VERTICALLY, IN OTHER WORDS, ONE BAY (OR ANY NUMBER DESIRED) CAN BE INCREASED VERTICALLY WITHOUT AFFECTING THE REST OF THE STRUCTURE. IN AN AREA WHERE LAND IS LIMITED, AS IN AN URBAN SITUATION, THIS BECOMES AN IMPORTANT CONSIDERATION IN THE OVERALL GROWTH PATTERN.



VERTICAL FLEXIBILITY

CIRCULATION

CIRCULATION, BOTH VERTICAL AND HORIZONTAL, SHOULD BE BASED ON THE PLANNING MODULE. IN OTHER WORDS, IT WILL BE PARTIAL, COMPLETE OR A COMBINATION OF MODULES BOTH VERTICALLY AND HORIZONTALLY. THE NATIONAL BUILDING CODE REQUIRES VARIOUS WIDTHS AND FREQUENCIES OF EXIT STAIRS DEPENDING ON THE DENSITY AND OCCUPANCY OF A BUILDING. THESE MUST BE LOCATED SO THAT THE MAXIMUM DISTANCE FROM ANY POINT IN A GIVEN FLOOR AREA TO AN EXIT DOORWAY MEASURED ALONG THE LINE OF TRAVEL (SEE DRAWING ONE) DOES NOT EXCEED:

75 FEET	HIGH HAZARD OCCUPANCY
100 FEET	ASSEMBLY, CLASSROOM
150 FEET	OFFICE SPACE

THE CODE ESTABLISHES THE FOLLOWING TO DETERMINE STAIR WIDTH OF EXITS FOR THE VARIOUS OCCUPANCIES:

ASSEMBLY	40 SQ.FT./PERSON
CLASSROOM	40 SQ.FT./PERSON
OFFICE	100 SQ.FT./PERSON

A UNIT OF STAIRWAY WIDTH USED AS A MEASURE OF EXIT CAPACITY IS 22 INCHES. THE NUMBER OF OCCUPANTS PER UNIT OF EXIT WIDTH FOR VARIOUS OCCUPANCIES ARE:

ASSEMBLY	60 OCCUPANTS/22 IN. EXIT WIDTH
CLASSROOM	60 OCCUPANTS/22 IN. EXIT WIDTH
HIGH HAZARD	30 OCCUPANTS/22 IN. EXIT WIDTH

CORES

THE CORES SERVE AS THE VERTICAL CIRCULATION CHANNELS. NOT ONLY CAN THE CORES CARRY THE STAIRS AND ELEVATORS, BUT THEY MAY ALSO CARRY AIR HANDLING EQUIPMENT, PIPING, AND ELECTRICAL FACILITIES OR ANY OTHER VERTICAL ELEMENT.

THE BUILDING CODE DICTATES THE MINIMUM NUMBER OF CORES WITH THE MAXIMUM SPACING FOR A GIVEN BUILDING OCCUPANCY. THIS CAN CHANGE FROM AREA TO AREA WITHIN A BUILDING. THE CORE FREQUENCIES AND THEIR COMPOSITE FORM IS ALSO DEPENDENT UPON THE CONFIGURATION OF THE BUILDING. SINCE THE CORES MUST ACHIEVE A CERTAIN DEGREE OF FLEXIBILITY, THEY WOULD BENEFIT FROM THE MODULAR PLANNING APPROACH USED IN THE REST OF THE BUILDING. A 12 X 12 STRUCTURAL MODULE WILL ACCOMMODATE A MINIMUM STAIRWAY. THE ADDITION OF MODULES WILL PROVIDE SPACE FOR ADDITIONAL EQUIPMENT AND EVENTUALLY A COMPLETE CORE. (SEE DRAWING TWO.) THE COMPLETE CORE IS A CONGLOMERATION OF ALL THE VERTICAL SERVICES CONCENTRATED IN THE LEAST AREA CAPABLE OF PROVIDING THE NECESSARY SERVICES.

THE COMPLETE CORE WOULD INCLUDE:

FIRE STAIRS

ELEVATORS (PASSENGER, FREIGHT)

TELEPHONES

ELECTRICAL

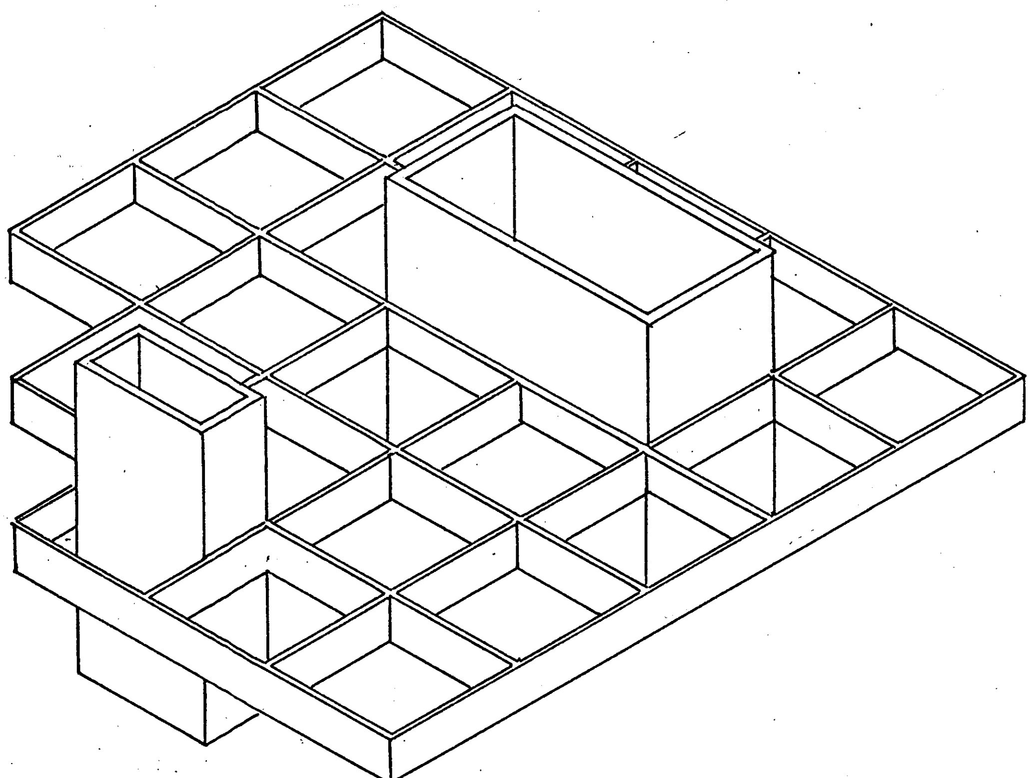
JANITORIAL SPACE

THE LAVATORIES DO NOT NECESSARILY HAVE TO OCCUR IN THE CORE. ALTHOUGH IT WOULD BE BEST TO KEEP ALL THE PLUMBING EQUIPMENT IN THE SAME AREA, THE LAVATORIES CAN OCCUR AT OTHER PLACES WITHIN THE BUILDING, BUT SUBJECT TO THE PLANNING MODULE ESTABLISHED. A 12 X 24 MODULE WILL PROVIDE A MEN'S OR WOMEN'S SINGLE GROUP MODULE LAVATORY WHICH CONTAINS 2 WCS, 2 URS, AND 3 LAVS.

THE CORES CAN EITHER SERVE AS A STRUCTURAL MEMBER IN THE BUILDING OR CAN BE INDEPENDENT OF THE STRUCTURE.

IN THE PROPOSED DESIGN SOLUTION THE MECHANICAL COLUMN CORE DEFINES A FIXED PATTERN ALTERNATING EVERY OTHER BAY IN ONE DIRECTION (SEE DRAWING ONE). THE CORE COMPONENTS ARE INDEPENDENT OF THIS PLACEMENT AND OCCUR AS DICTATED BY CODE. THE DIMENSIONS OF THE CORES ARE BASED ON THE 12 X 12 MODULE. THIS ALLOWS THE VERTICAL RUN OF A MINIMUM STAIR TO FIT INTO A 12 X 12 MODULE. A 12 X 12 WILL ALSO ACCOMMODATE A FREIGHT ELEVATOR WHILE A 12 X 24 WILL ACCEPT THREE PASSENGER ELEVATORS.

THE CORES TOO BECOME PART OF THE OVERALL DIMENSIONAL SYSTEM.



CORE PENETRATION

STRUCTURE

"THERE CAN BE NO ARCHITECTURE WITHOUT TECHNOLOGY TO TRANSLATE ARCHITECTURAL CONCEPTS INTO PHYSICAL REALITY."[6] THE INITIAL GOAL OF THIS STUDY IS TO USE TECHNOLOGICAL DEVELOPMENTS AVAILABLE AND ANTICIPATED TO DEVELOP A BUILDING SYSTEM THAT WOULD OPTIMIZE STRUCTURAL EFFICIENCY, PROVIDE A CONSTANT CEILING HEIGHT, AND PROVIDE SPACE IN CONJUNCTION WITH THE FLOOR SYSTEM FOR MECHANICAL AND UTILITY SERVICES.

ONE AND TWO-WAY STRUCTURAL SYSTEMS BECAME THE BASIS OF INVESTIGATION FOR DEVELOPING AN INTEGRATED BUILDING SYSTEM. A ONE-DIMENSIONAL RESISTING STRUCTURE (ONE-WAY) IS A SOMEWHAT INEFFICIENT SYSTEM OF TRANSMITTING LOADS TO THEIR SUPPORTS. FOR EXAMPLE, UNDER LOAD ONE BEAM MAY BE CARRYING THE TOTAL LOAD WHILE AN ADJACENT BEAM MAY BE UNSTRESSED. IN OTHER WORDS, THE GROUP OF BEAMS DOES NOT WORK AS A WHOLE IN CARRYING THE LOAD. EACH BEAM MUST THEN BE DESIGNED TO CARRY A DESIGNED MAXIMUM LOAD RESULTING IN AN INEFFICIENT USE OF MATERIAL, SINCE THEY SHARE NO WORK.

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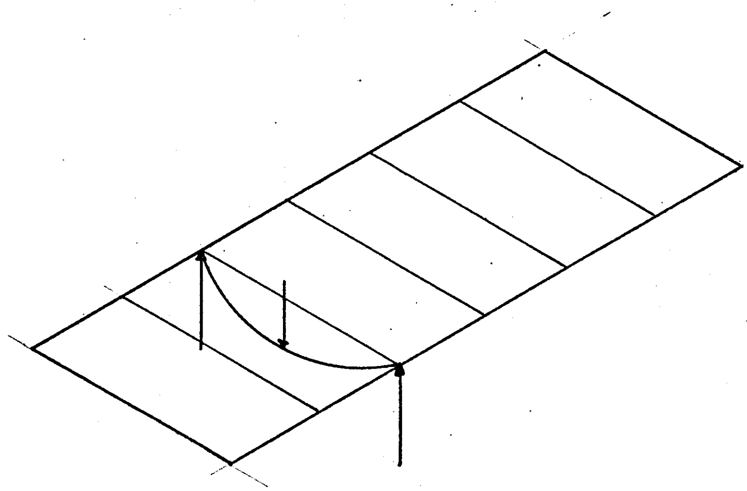
[6] Curt Seigel, Structure and Form. trans. by Thomas E. Burton (New York: Reinhold Publishing Corporation, 1963), p. 7.

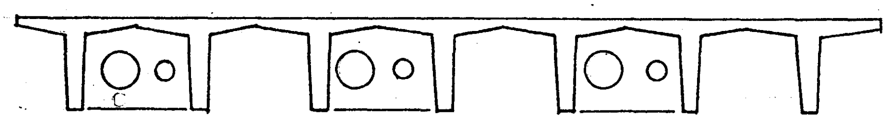


ONE DIMENSIONAL RESISTING SYSTEM

TO SATISFY THE DESIGN REQUIREMENTS OF A CONSTANT CEILING HEIGHT THE ONE-WAY SYSTEM MUST USE A GIRDER THAT IS SHORTER IN LENGTH THAN THE BEAMS. THIS, OF COURSE, PRODUCES A RECTANGULAR STRUCTURAL AND CONSEQUENTLY A RECTANGULAR PLANNING GRID. THIS MAY OR MAY NOT BE A PROBLEM, DEPENDING UPON THE SOLUTION DESIRED. IT DOES, HOWEVER, SOMEWHAT LIMIT A MODULAR GROWTH PATTERN.

MECHANICALLY THERE IS BOTH ADVANTAGE AND DISADVANTAGE TO THE RECTANGULAR GRID. THE MECHANICAL SYSTEMS

(AIR, PIPES, ELECTRICAL) CAN BE COMBINED WITH THE LIGHTING INTO A UNIT THAT USES THE STRUCTURE AS AN ENCLOSURE (SEE DIAGRAM).



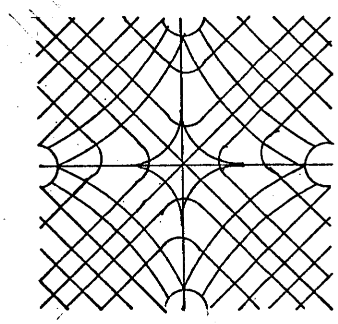
THIS DENIES THE POSSIBILITY OF MECHANICAL PENETRATION IN TWO DIRECTIONS EASILY RESULTING IN A LOSS OF FLEXIBILITY MECHANICALLY.

THE ONE-WAY SYSTEM, DESPITE SOME LIMITATIONS, HAS THE ADVANTAGE OF BEING COMPOSED OF EASILY HANDLED, EASILY ERECTED MEMBERS WITH SIMPLE CONNECTIONS. THESE CONSTRUCTION ADVANTAGES ARE BY FAR THE MOST IMPORTANT FEATURE OF THE ONE-WAY SYSTEM IN TERMS OF A BUILDING DEVELOPMENT.

THE TWO-WAY DIMENSIONAL RESISTING STRUCTURE (TWO-WAY) WILL TRANSMIT A LOAD EQUALLY TO THE SUPPORTS THROUGH BOTH MEMBERS, PROVIDING THESE MEMBERS ARE THE SAME. IN THIS CASE, AS OPPOSED TO A ONE-WAY, THE BEAMS SHARE THE LOAD. IF A BEAM IS DESIGNED IN ACCORDANCE

WITH THIS PRINCIPLE THE RESULT WILL REPRESENT A SAVING OF MATERIAL.

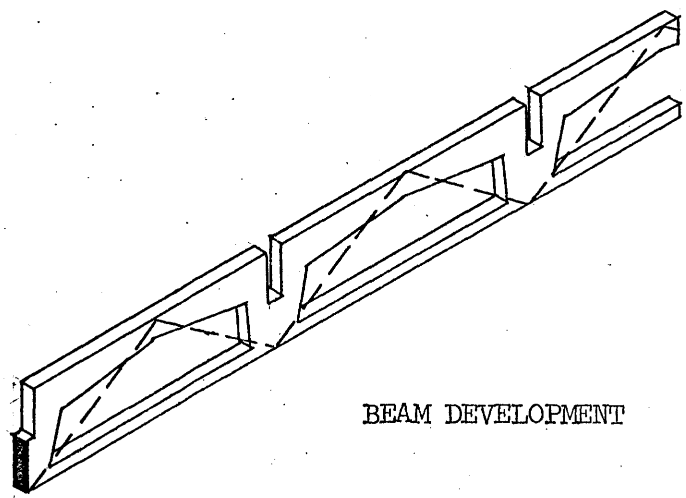
THE ULTIMATE EXAMPLE OF THE TWO-WAY FORCE TRANSFER IS A FLAT SLAB WHERE THE SLAB ACTION IS DISTRIBUTED AS IF BY AN INFINITE NUMBER OF BEAMS (SEE DIAGRAM).



UPON CONSIDERING THE IMPLICATIONS OF BOTH A ONE-WAY AND A TWO-WAY SYSTEM IT WAS FOUND THAT A COMBINATION OF THE CONSTRUCTION SIMPLICITY OF A ONE-WAY SYSTEM AND THE RELATIVE STRUCTURAL EFFICIENCY OF A TWO-WAY SYSTEM WOULD PROVIDE AN EXCELLENT SOLUTION FOR A LABORATORY-RESEARCH BUILDING. THE SYSTEM DEVELOPED CONSISTS OF A PERIMETER GIRDER SYSTEM, A LOWER BEAM, AN UPPER BEAM, PRECAST FLOOR SLABS, AND PRECAST COLUMNS (SEE PHOTOGRAPH ONE).

THE GIRDERS PROVIDE A BASE TO WHICH THE LOWER BEAM

IS ATTACHED. THE UPPER BEAM IS THEN PLACED ON THE LOWER AND IS POSTTENSIONED THROUGH THE GIRDER. THIS PROVIDES THE SYSTEM WITH THE TWO-WAY ACTION (PHOTO SEQUENCE TWO-FOUR). THE DESIGN OF THE GIRDER AND THE BEAMS IS BASED ON THE PRINCIPLE OF THE TRUSS. THE PURE TRUSS FORM HAS BEEN MODIFIED TO PROVIDE MAXIMUM MECHANICAL AND SERVICE OPENINGS THROUGH THE STRUCTURE IN BOTH DIRECTIONS.

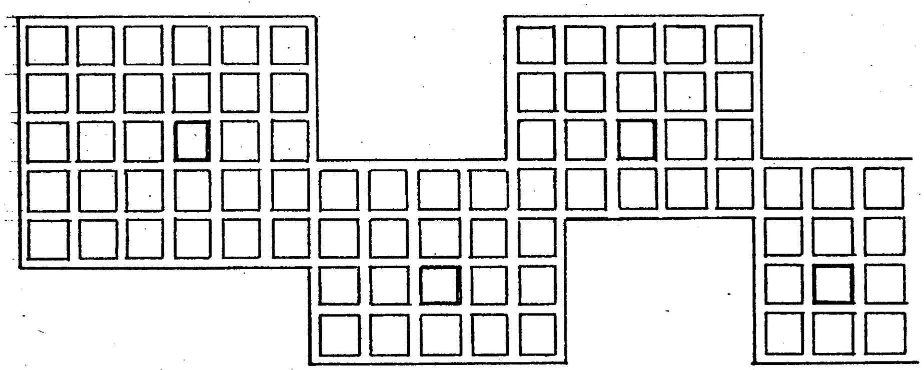


BEAM DEVELOPMENT

THE INTERSECTION OF THE BEAMS OCCURS AT 12' O.C. AND THIS PROVIDES A 12' PLANNING MODULE. THIS TWELVE FOOT SQUARE MODULE ALSO ALLOWS ADEQUATE ROOM TO REMOVE, SERVICE, AND ADD MECHANICAL EQUIPMENT WITH A MAXIMUM OF WORKING AREA.

THE NEW LABORATORY BUILDINGS AT BIRMINGHAM UNIVERSITY IN ENGLAND REPRESENT A SIMILAR APPROACH IN CONCEPT, BUT ARE SMALLER IN SCALE. PHILLIP DAWSON, THE DESIGNER

IN THE OVE ARUP OFFICE, DESCRIBED THE BUILDING THIS WAY: "A LABORATORY BUILDING IS 'PACKAGED SERVICES' AND STRUCTURE BECOMES SUBORDINATE... TO A CONTINUOUS HORIZONTAL AND VERTICAL NETWORK OF SPACES, A NETWORK OF STRUCTURAL DISCONTINUITY."



AT THE PERIMETER OF EACH 60 X 60 BAY IS A MECHANICAL COLLECTION CHANNEL WHERE ALL SERVICES ARE COLLECTED AND CARRIED TO THE CORE. A SQUARE BAY ALLOWS FOR THE POSSIBILITY OF GROWTH IN TWO DIRECTIONS ALSO.

THE TOTAL FLOOR SYSTEM WAS DESIGNED AS 100 PSF. IN SOME AREAS OF THE BUILDING THIS MAY CAUSE A CONDITION WHERE THE STRUCTURE IS OVER DESIGNED FOR THE WORK IT IS DOING. HOWEVER, IN KEEPING WITH THE CONCEPT OF A FLEXIBLE METHOD OF BUILDING THE FLOOR SYSTEM MUST BE

DESIGNED TO ACCEPT INITIALLY UNANTICIPATED CHANGES AND STRUCTURAL EFFICIENCY MUST BE WEIGHED AGAINST FLEXIBILITY. SEVEN FLOORS WAS THE ASSUMED HEIGHT OF THE BUILDING. SINCE EACH BAY IS INDEPENDENT OF THE NEXT, A SELECTED AREA COULD GO UP SEVERAL TIMES THIS HEIGHT WITH A REDESIGNED COLUMN AND WINDLOAD CONTROLS.

FABRICATION

HAVING ASSUMED CONCRETE AS A BUILDING MATERIAL DUE TO ITS FIRE RESISTANT QUALITIES, PLASTICITY, AND ABILITY TO ACT AS A FINISHED MATERIAL, A DECISION MUST BE MADE WHETHER TO USE IT IN A CAST-IN-PLACE OR PRECAST FORM.

IN THE FINAL ANALYSIS IT IS MAINLY A MATTER OF ECONOMY AS TO WHICH TECHNIQUE IS USED. SINCE EACH HAS ADVANTAGES AND DISADVANTAGES, A DECISION MUST BE BASED ON THE INTENDED INDIVIDUAL PROJECT; OR A BUILDING SYSTEM CAN BE DEVELOPED USING EITHER TECHNIQUE AS A BASIS FOR DESIGN.

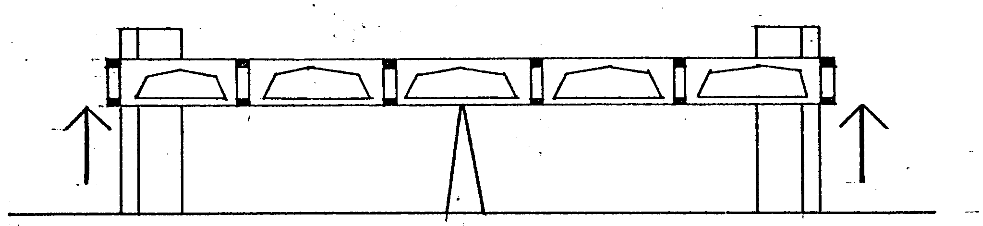
CAST-IN-PLACE CONCRETE NEGATES THE NEED TO TRANSPORT FINISHED MEMBERS FROM THE FACTORY TO THE SITE. ACCORDING TO THE BATTLE INSTITUTE REPORT, A STUDY ON THE CURRENT STATE OF BUILDING, IT WAS FOUND THAT THE EFFECTIVE ECONOMIC RADIUS OF A PRECAST PLANT IS ABOUT 30 OR 40 MILES. (THIS DISTANCE MAY BE INCREASED IN A LARGE METROPOLITAN SITUATION.) THIS FACTOR MAY BE A MAJOR CONSIDERATION IN THE FABRICATION METHOD SELECTED. POURED CONNECTIONS ALLOW CONTINUITY THROUGHOUT THE STRUCTURE TO BE MORE EASILY ATTAINED DUE TO THE LACK OF DIFFICULT CONNECTION DETAILS.

DESPITE SOMEWHAT MORE LABORIOUS CONNECTIONS, PRECAST CONCRETE DUE TO ITS MANUFACTURE IN A FACTORY SITUATION HAS MOST OF THE ADVANTAGES USUALLY ASSOCIATED WITH FACTORY FABRICATION. LABOR IS USED MORE EFFICIENTLY, QUALITY CONTROL IS HIGHER, FINISHES ARE BETTER, DIFFICULT SHAPES ARE MORE EASILY FABRICATED, AND WEATHER IS NOT A CONTROLLING FACTOR IN THEIR MANUFACTURE.

ERECTION

FABRICATION, TRANSPORTATION, AND ERECTION PROCEDURES ARE CONSIDERABLY SIMPLIFIED BY THE USE OF ONE-WAY ELEMENTS. THEY REQUIRE SIMPLE LINEAL FORMS THAT NEED MINIMUM FABRICATION AND ERECTION COSTS. NO SPECIAL TRANSPORTATION MEASURES ARE NECESSARY BECAUSE THE HEAVIEST MEMBER WEIGHS ONLY 25 KIPS AND IS EASILY WITHIN THE TRANSPORTABLE ROAD REGULATIONS.

THE ERECTION PROCEDURE SHOWS TO BEST ADVANTAGE THE INHERENT QUALITIES OF A ONE-WAY MEMBER. LIFTING AND ATTACHMENT PROCEDURES ARE SIMPLE AND UNCOMPLICATED. THE ENTIRE BAY MAY BE CONSTRUCTED ON THE GROUND AND THEN LIFTED UP AROUND THE COLUMNS AND ATTACHED. THIS PROCEDURE REQUIRES NO SCAFFOLDING. IF, HOWEVER, IT IS CHOSEN TO ERECT IT IN PLACE, THE GIRDERS ACT AS SUPPORT FOR THE ENDS OF THE BEAM WHILE A CENTRAL SCAFFOLDING SYSTEM IS ALL THAT IS NEEDED (SEE DIAGRAM).



ERECTION PROCEDURE

ERECTION PROCEDURE

1. PRECAST ALL COMPONENTS AND DELIVER TO THE SITE.
2. POUR ALL COLUMN FOOTINGS AND FOUNDATION WALLS.
3. GROUT AND PLACE PRECAST COLUMN SECTIONS.
4. PLACE AND ASSEMBLE PERIPHERY GIRDER MEMBERS.
5. PLACE LOWER BEAMS A (LOWER BEAM INITIAL STAGE) IN POSITION AND WELD CONNECTIONS.
6. PLACE UPPER BEAMS B (UPPER BEAM INITIAL STAGE) ON BEAMS A. GROUT CONNECTIONS AT EACH JOINT AND WELD CONNECTIONS AT THE GIRDERS.
7. THREAD POST-TENSIONING CABLE THROUGH BOTTOM CHORD OF BEAM B.
8. POST TENSION.
9. PLACE PRECAST FLOOR PANELS IN POSITION.
10. LIFT ENTIRE BAY AT GIRDERS.
11. ATTACH ENTIRE BAY AT COLUMN POINTS BY WELDING AND ATTACHMENT KEYS.
12. INSTALL ELECTRICAL SERVICE AND POUR TOPPING.
13. RETENSION CABLES THROUGH GIRDER.

ENVIRONMENTAL
CONTROL

THE DECISION TO SELECT A PARTICULAR AIR HANDLING SYSTEM SHOULD BE CONSIDERED ON THE BASIS OF BUILDING USE, VARIATION IN FUNCTION DESIRED, INITIAL COST, OPERATIONAL COST, DIMENSIONAL LIMITATIONS, INSTALLATION METHODS, AND ADAPTATION TO CHANGE.

ON THIS BASIS, THREE SYSTEMS WERE CHOSEN, THE SINGLE-AIR, DUAL-AIR AND PRIMARY-AIR SYSTEMS WERE INVESTIGATED.

SINGLE-AIR SYSTEMS

A SINGLE AIR SUPPLY TO THE CONDITIONED SPACE PERFORMS THE HEATING, COOLING, HUMIDIFICATION, AND DEHUMIDIFYING FUNCTIONS. METHODS OF OBTAINING ZONE OR INDIVIDUAL ROOM CONTROL ARE:

REHEAT (AT EACH ZONE OR ROOM)

AIR IS SUPPLIED AT DEW-POINT DRY-BULB TEMPERATURE LOW ENOUGH TO BALANCE WITH MAXIMUM EXPECTED COOLING LOAD IN ANY SPACE, AND REHEAT IS SUPPLIED IN THE BRANCH DUCT TO EACH ZONE AS REQUIRED TO MATCH THE ACTUAL SENSIBLE HEAT LOAD. THIS SYSTEM PROVIDES EXCELLENT CONTROL UNDER HIGHLY VARIABLE CONDITIONS.

VOLUME DAMPERS (AT EACH ZONE OR ROOM)

AIR TO EACH ZONE OR ROOM IS THROTTLED ACCORDING TO THE LOAD. EXCESSIVE THROTTLING WILL IMPAIR VENTILATION AND DEHUMIDIFICATION CAPACITY. THE STATIC PRESSURE BALANCE MAY BE IMPAIRED CAUSING AN INCREASE IN THE AIR VOLUME IN ONE ZONE DUE TO A REDUCTION IN ANOTHER.

VOLUME DAMPERS AND REHEAT (AT EACH ROOM)

THIS IS A COMPROMISE BETWEEN A AND B BY PROVIDING VOLUME CONTROL UNTIL THE AIR IS REDUCED TO SOME PREDETERMINED MINIMUM QUANTITY, AFTER WHICH REHEAT CONTROL IS USED.

DUAL-AIR SYSTEMS

THESE SYSTEMS PROVIDE THE CHOICE OF HEATING OR COOLING AS REQUIRED BY DIFFERENT ZONES THROUGH DUAL-AIR STREAMS. AIR IS SUPPLIED TO THE TOW AIR STREAMS AT DIFFERENT CONDITIONS (USUALLY ONE HOT, THE OTHER COLD) AND MIXED BY PROPORTIONING DAMPERS EITHER IN THE ROOM OR UPSTREAM IN A PLENUM. IF DESIRED, MIXING MAY BE PERFORMED AT THE APPARATUS WITH ONLY A SINGLE DUCT EXTENDING TO EACH ZONE. TO MAINTAIN CONDITIONS AT ALL TIMES, THE COOLING CONDITIONER AND DUCT MUST BE SIZED FOR THE MAXIMUM COOLING LOAD THAT EXISTS WHEN NO HEATING IS REQUIRED FROM THE DUCT, AND VICE VERSA. THIS MEANS THAT FOR ANY SYSTEM WHERE THERE IS A WIDE VARIATION IN THE COOLING AND HEATING REQUIREMENTS

AMONG THE SPACES SERVED, EACH CONDITION AND DUCT WILL HAVE TO BE SIZED TO CARRY POSSIBLY 75% OR MORE OF THE MAXIMUM LOAD.

PRIMARY AIR DUCT SYSTEM

BY PHYSICALLY SEPARATING THE SENSIBLE AND LATENT HEAT-REMOVING FUNCTIONS, THROUGH THE USE OF SEPARATE HEAT EXCHANGERS, THESE SYSTEMS HAVE IMPORTANT ADVANTAGES IN MULTI-ROOM COMFORT APPLICATIONS WHERE RELATIVELY HIGH SENSIBLE HEAT FACTORS OCCUR. TEMPERATURE IS CONTROLLED BY THROTTLING THE SOURCE OF SENSIBLE COOLING OR HEATING, WHILE THE HUMIDITY IS MAINTAINED WITHIN ACCEPTABLE LIMITS BY FIXING THE DEW POINT OF THE PRIMARY AIR SUPPLY. SINCE A COIL IN EACH ROOM PERFORMS THE SENSIBLE HEATING AND COOLING, ONLY PRECONDITIONED VENTILATION AIR AT CONTROLLED DEW POINT IS SUPPLIED FROM THE CENTRAL APPARATUS, USUALLY THROUGH HIGH VELOCITY CONDUITS. THERE IS A GREAT SAVING IN SPACE WITH THIS SYSTEM, BUT IT HAS HIGH OPERATING COST AND LIMITED FLEXIBILITY.

CONSIDERING THE HEAVY AIR SUPPLY AND DEMAND LOADS IN A BUILDING OF THIS NATURE, THE AIR HANDLING SYSTEM WAS DESIGNED FOR A 2 CFM. CAPACITY. THE SINGLE-AIR SYSTEM WITH VOLUME CONTROL AND REHEAT AT EACH ROOM WAS FOUND TO BE

THE MOST SATISFACTORY SOLUTION. USING THIS SYSTEM HELPED REDUCE THE OVERALL DUCT SIZE WHICH IS AN IMPORTANT CONSIDERATION IN A CASE WHERE MANY SERVICES MUST PENETRATE THE STRUCTURE AT ANY GIVEN POINT. THE PROBLEMS OF ESTABLISHING SATISFACTORY SOUND CONTROL REQUIRES AN ATTENUATION SYSTEM, LINING OF THE DUCTS AND EQUIPMENT ISOLATION.

THE VERTICAL MECHANICAL SHAFTS OCCUR AT THE CORES AS DOES THE PIPING AND OTHER LAB SERVICES. IT PROCEEDS FROM HERE DOWN THE COLLECTION CHANNEL TO EACH BAY. EACH MECHANICAL CORE ALTERNATES TO CARRY SUPPLY AND RETURN. THIS SITUATION BRINGS UP AN INCONSISTENCY. AT THE MECHANICAL CORE, THE LARGEST DUCTS OCCUR AND REDUCE IN SIZE AS THEY PROCEED DOWN THE MECHANICAL COLLECTION CHANNEL. A STAGGERED CORE SYSTEM WOULD HAVE ELIMINATED THIS, BUT AT THE EXPENSE OF PLANNING FLEXIBILITY.

EACH 12 X 12 MODULE CONTAINS A SUPPLY AND RETURN OUTLET AS PART OF THE LIGHTING SUB-SYSTEM WHICH IS BASED ON A 6 X 6 GRID. THIS SUB-SYSTEM IS REMOVABLE AND ALLOWS A 12 X 12 OPEN SPACE FOR SERVICING, REPLACING OR ADDING NEW ON OLD EQUIPMENT. THIS OPEN SPACE WAS ALSO A CONSIDERATION IN THE SELECTION OF THE 12 X 12 STRUCTURAL MODULE.

CONCLUSION

THE PRIMARY EMPHASIS OF THIS STUDY HAS BEEN THE STRUCTURAL DEVELOPMENT OF A BUILDING SYSTEM.

OUR INCREASED DEMAND TO PROVIDE BUILDINGS NECESSITATES A METHOD OF CONSTRUCTION THAT MAXIMIZES ECONOMY AND EFFICIENCY IN LABOR AND MATERIAL. THE BUILDING SYSTEM IS AN ATTEMPT TO SOLVE THESE GOALS. COMBINED WITH THE ERECTION AND FABRICATION ADVANTAGES OF A ONE-WAY SYSTEM IS THE STRUCTURAL EFFICIENCY OF THE TWO-WAY SYSTEM. THIS WILL RESULT IN MORE FACTORY AND LESS ON-SITE WORK.

THE OVERALL GROWTH PATTERN IS OF A FLEXIBLE NATURE ALLOWING GROWTH IN TWO DIRECTIONS AT 90° TO EACH OTHER. VERTICAL FLEXIBILITY IS ALSO ACHIEVED BY THE DISCONTINUOUS 60' X 60' BAYS. THIS IS AN IMPORTANT CONSIDERATION WHEN DEALING WITH A LIMITED SITE.

THE SUBSYSTEMS SUCH AS LIGHTING, MECHANICAL DIFFUSION, GROWTH, AND PLANNING WERE ALL INVOLVED AS DETERMINANTS IN THE FINAL STRUCTURAL STATEMENT.

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APPENDIX

FOR STRUCTURAL CALCULATIONS REFER TO THE "COMPUTER SUPPLEMENT FOR INTEGRATED BUILDING SYSTEMS, COURSE 4.17," PREPARED BY PARTICIPATING MEMBERS OF THE MASTERS CLASS, SCHOOL OF ARCHITECTURE, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, ON FILE IN THE ROTCH LIBRARY.

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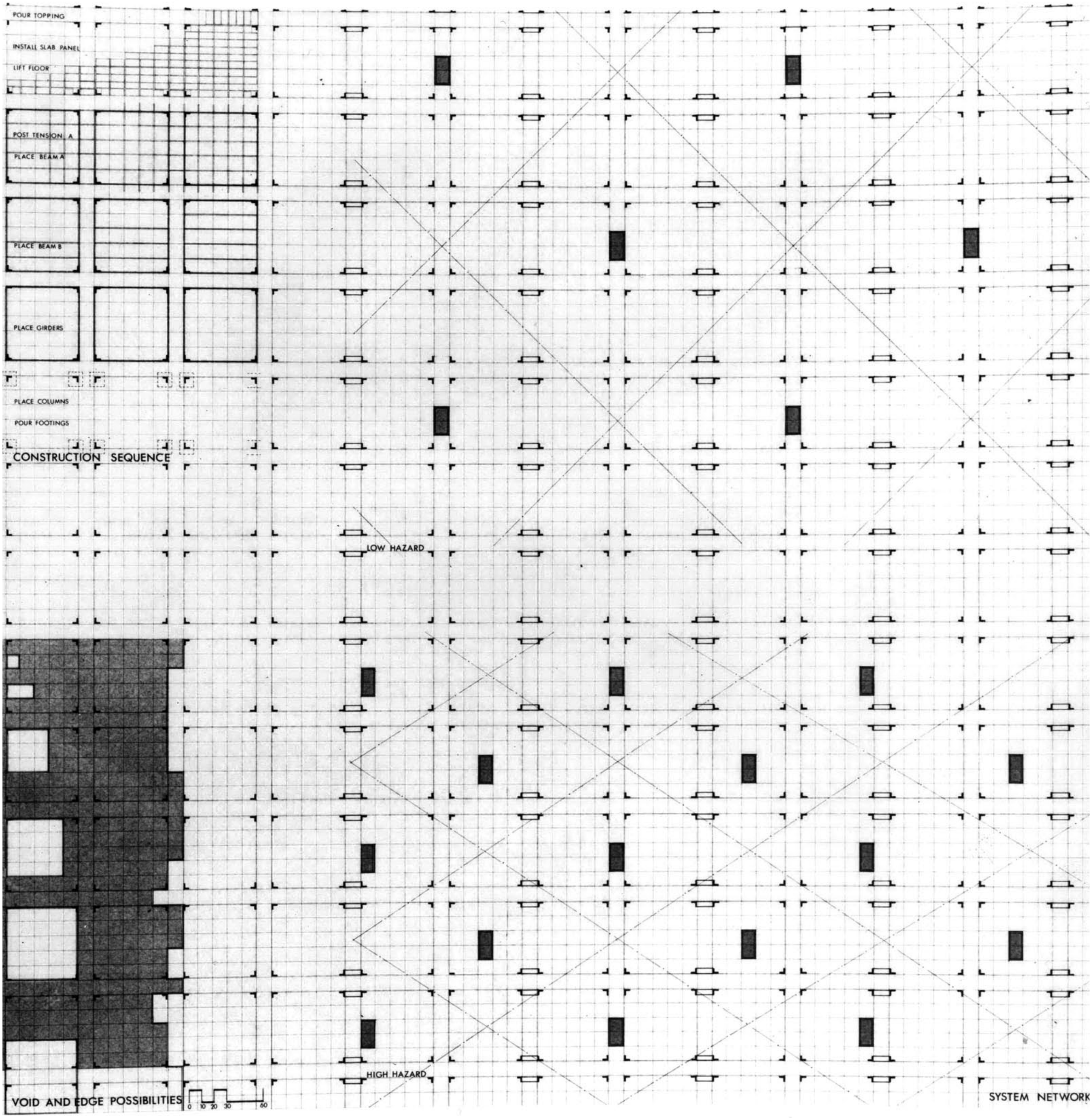

AN INTEGRATED BUILDING SYSTEM
MASTER OF ARCHITECTURE THESIS

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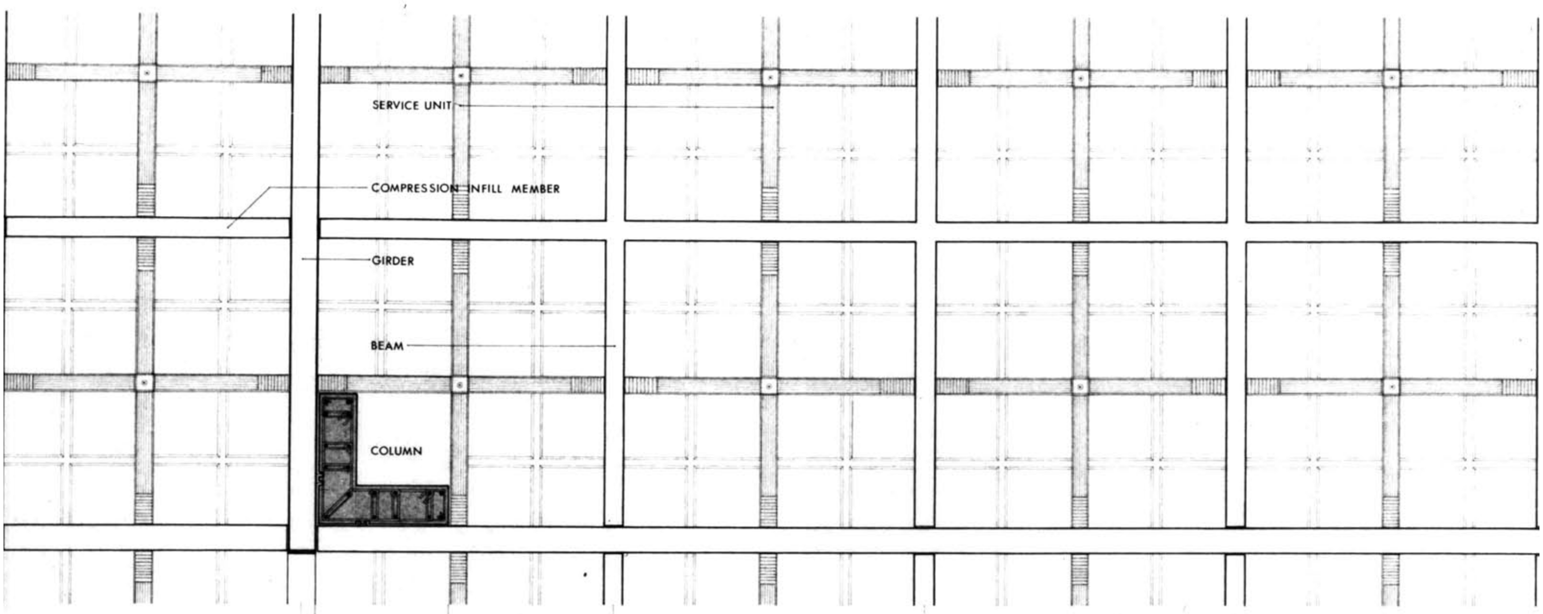
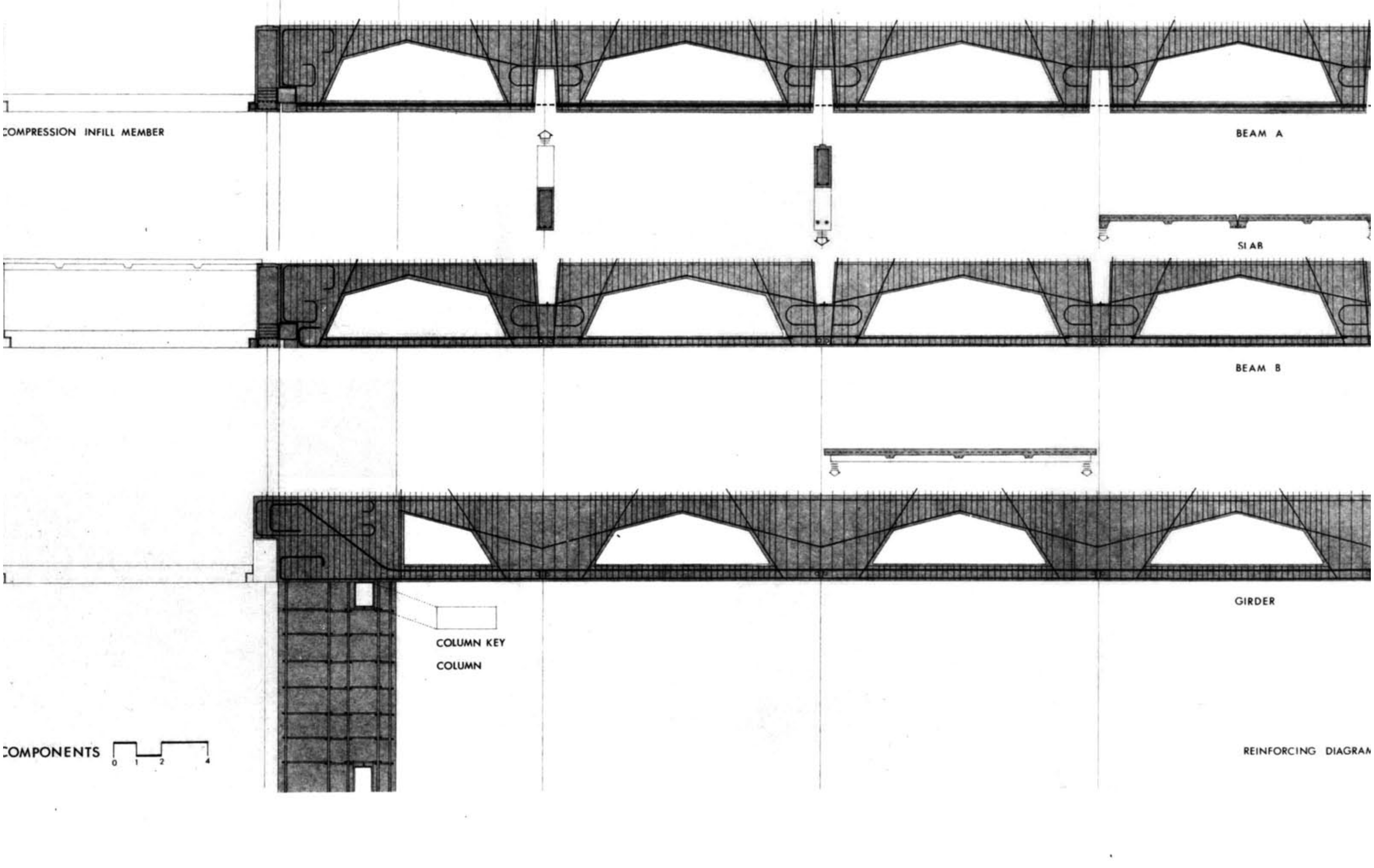
RONALD M. MARGOLIS FALL 1967



REFLECTED CEILING PLAN



COMPONENTS

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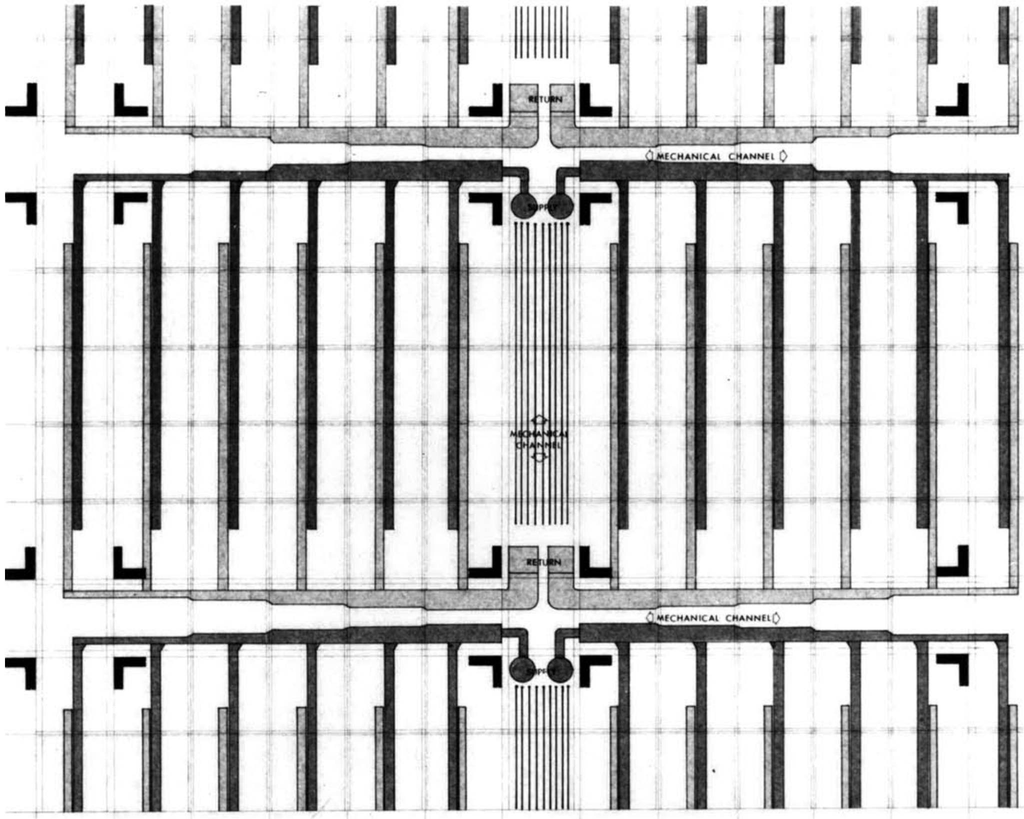

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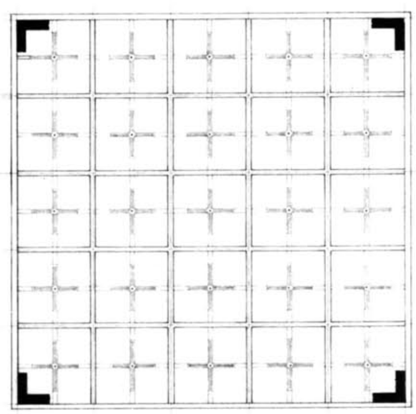

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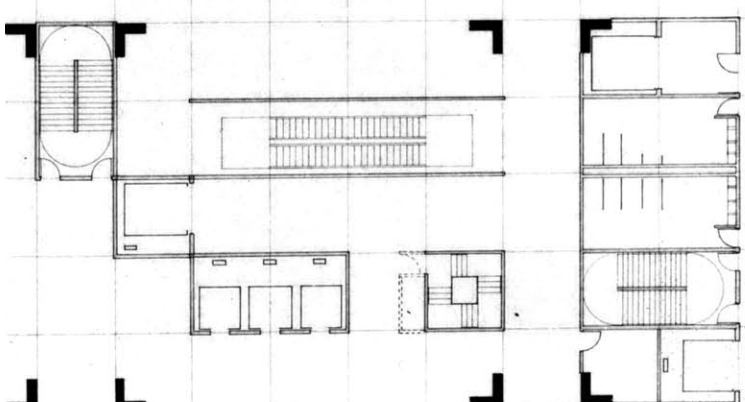
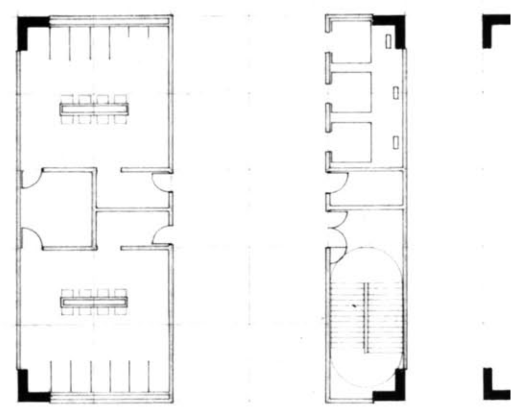


CORE COMPONENTS 0 2 4 8 16



TYPICAL CORES

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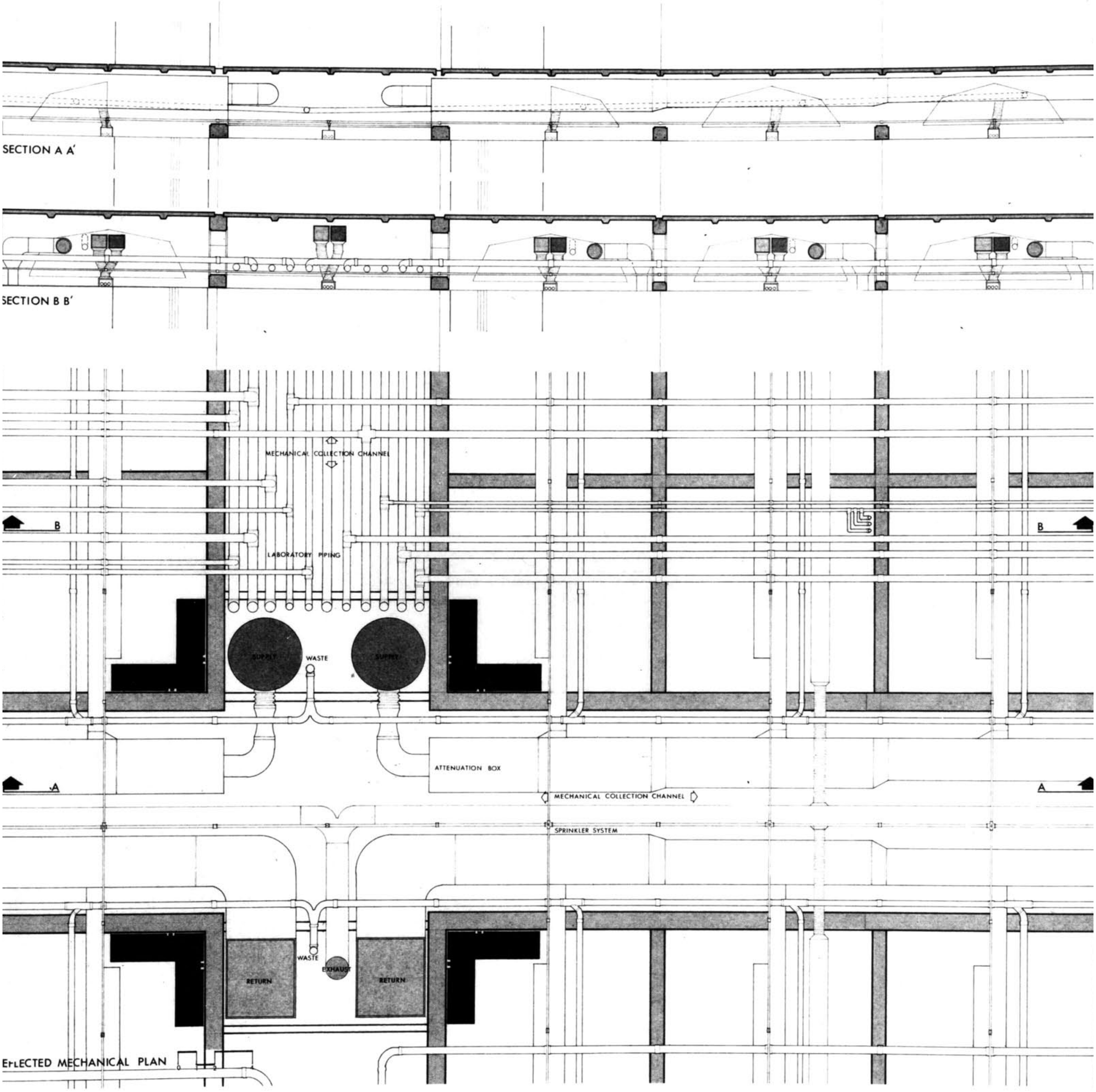

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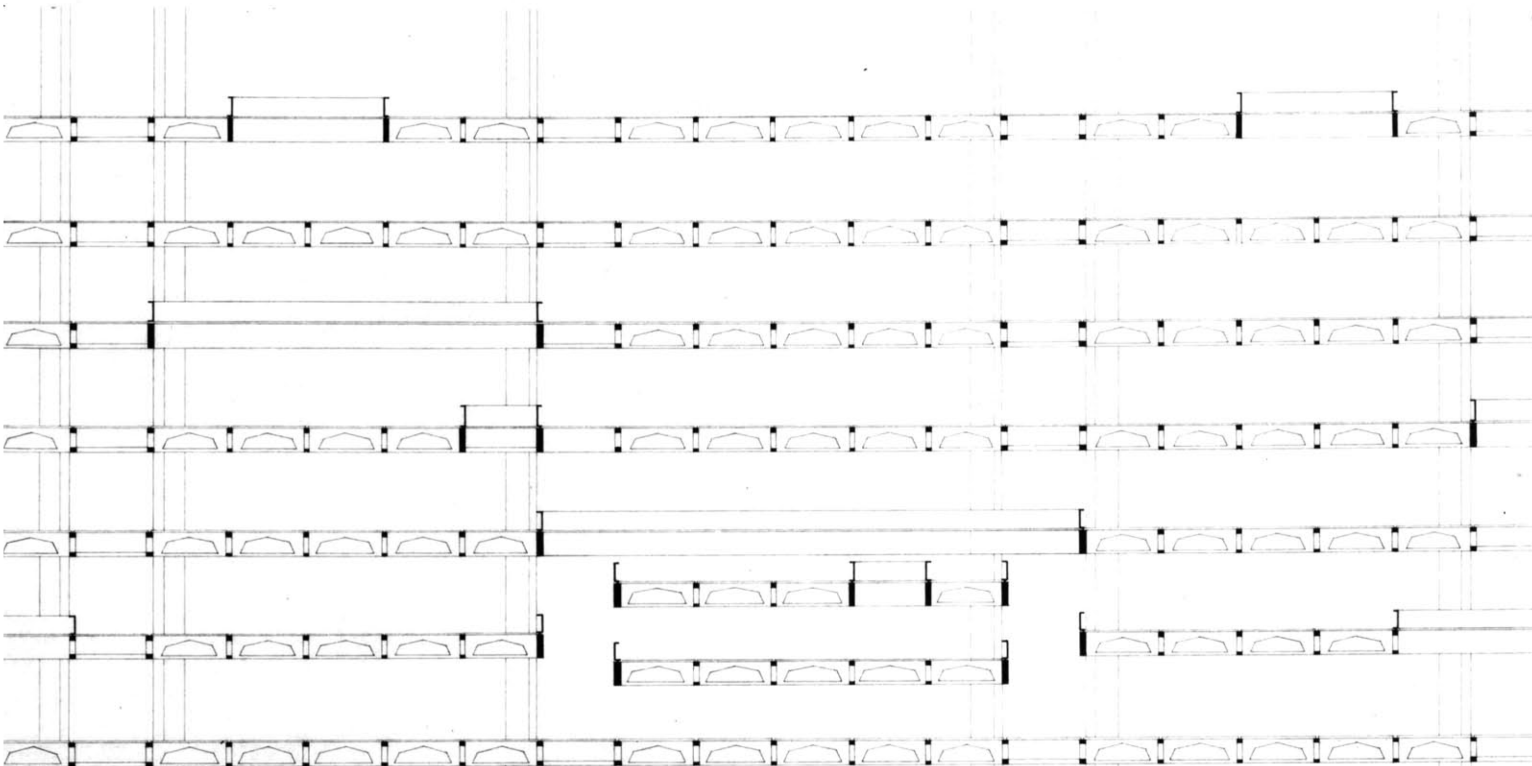

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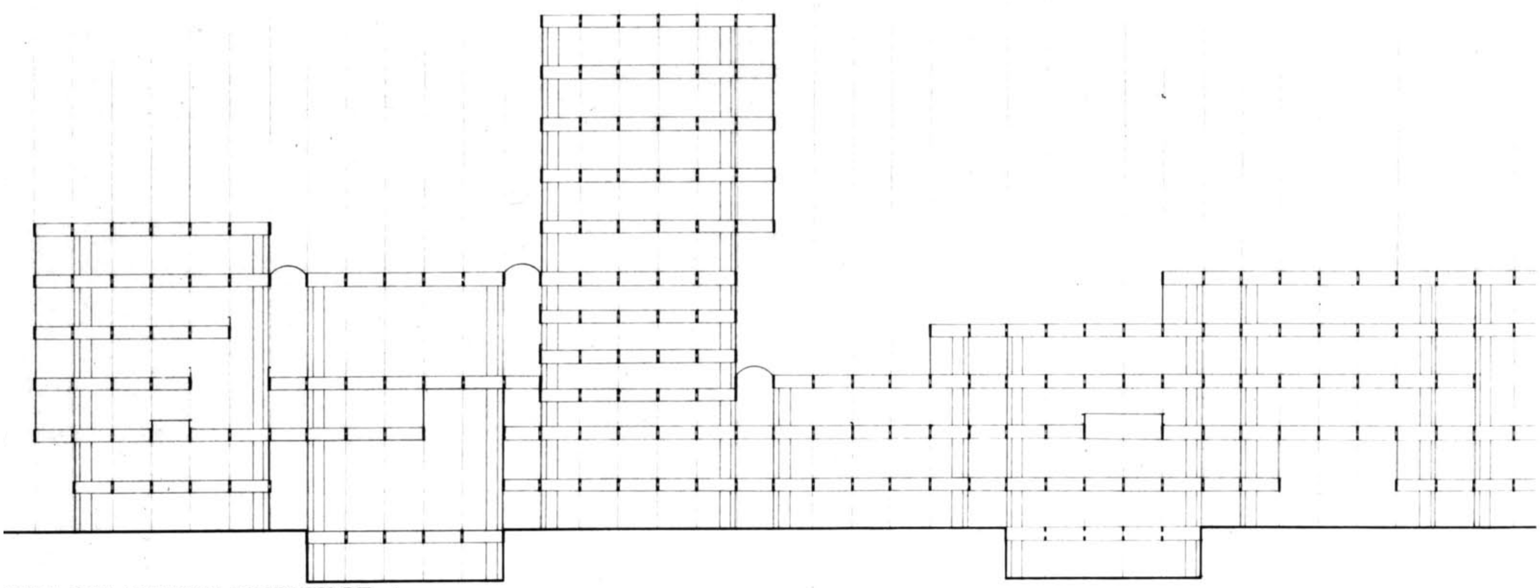

SYSTEM FORM AND SPATIAL POSSIBILITIES 0 2 4 8 16

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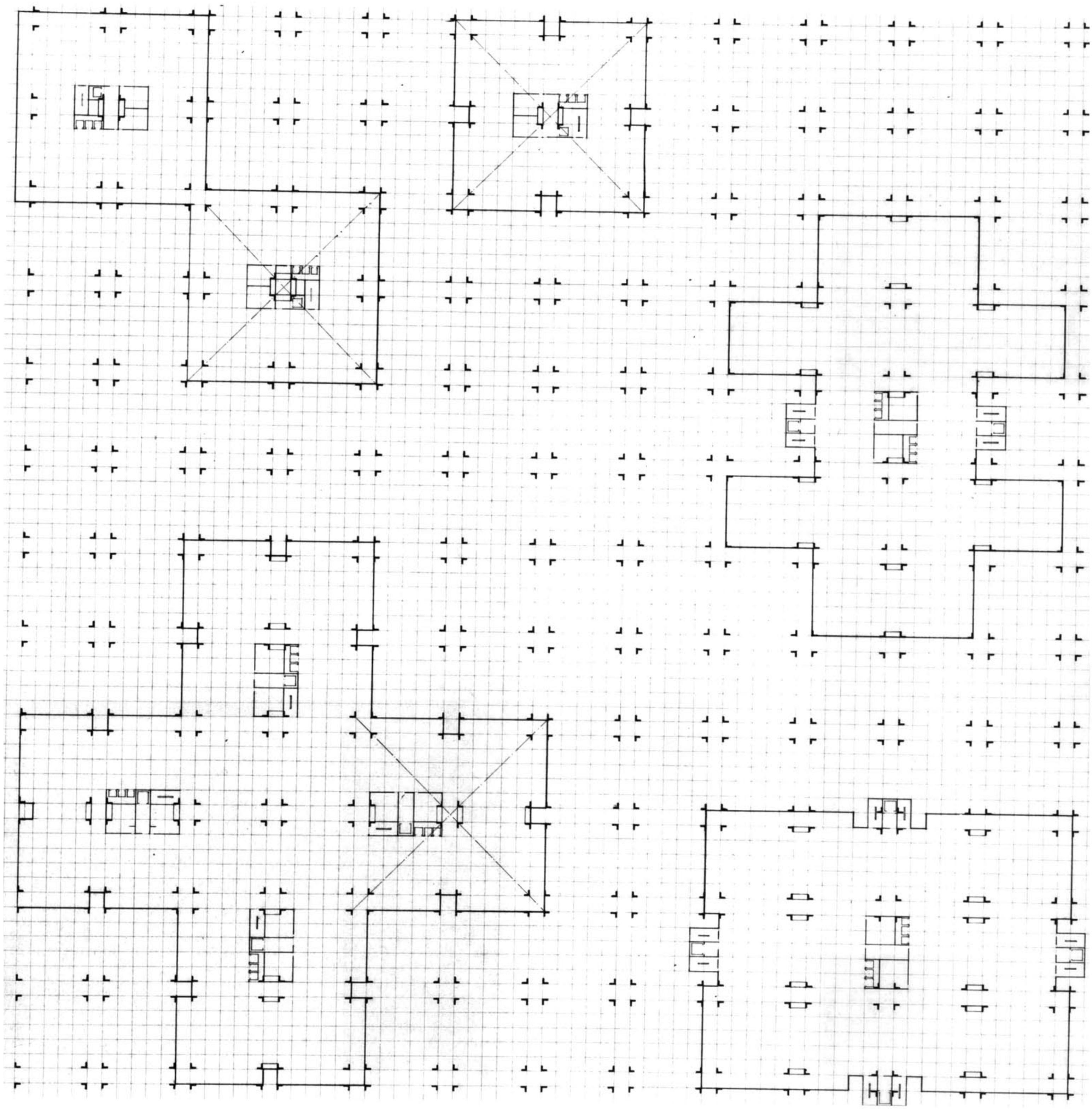

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