BUILDINGS AS INTEGRATED SYSTEMS

by

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1963

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE
DEGREE OF MASTER OF
ARCHITECTURE

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1968, [L. L. R.]

Signature of Author
Department of Architecture, June 1968

Certified by................................. Thesis Supervisor

Accepted by................................ Dean of the School of Architecture and Planning
Dear Mr. Madan:

I am writing further to my letter to you of January 20, 1970.

Your thesis remains incomplete—so incomplete, as a matter of fact, that there is no continuity. The appendix and bibliography are missing and the table of contents is highly inconsistent with the body of the thesis.

Please advise me on this so that I may report to the Archives.

Sincerely,

Pamela A. Bedrosian
Administrative Assistant

cc Miss Eleanor Bartlett
Dear Dean Lawrence B. Anderson:
School of Architecture and Planning
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

In partial fulfillment of the requirements for the degree of Master of Architecture, I hereby submit this thesis entitled, "BUILDINGS AS INTEGRATED SYSTEMS," as envisaged for and Indian University.

Respectfully,

Jitendra K. Madan
<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
</tr>
<tr>
<td>Acknowledgements</td>
</tr>
<tr>
<td>1. Introduction</td>
</tr>
<tr>
<td>2. Aims</td>
</tr>
<tr>
<td>3. Assumptions and Limitations</td>
</tr>
<tr>
<td>4. Concept</td>
</tr>
<tr>
<td>5. Planning Module</td>
</tr>
<tr>
<td>6. Linear or Non-Linear System</td>
</tr>
<tr>
<td>7. Structural Bay</td>
</tr>
<tr>
<td>8. The Construction Technique</td>
</tr>
<tr>
<td>9. The System</td>
</tr>
<tr>
<td>10. System Components</td>
</tr>
<tr>
<td>11. Network or Variations of Building Footprints</td>
</tr>
<tr>
<td>12. Structure</td>
</tr>
<tr>
<td>13. Erection Procedure</td>
</tr>
<tr>
<td>14. Frequency of Cores and Egress</td>
</tr>
<tr>
<td>15. Appendix</td>
</tr>
<tr>
<td>16. Bibliography</td>
</tr>
</tbody>
</table>
ABSTRACT

Buildings as Integrated Systems
Jitendra Kumar Madan

Submitted to the Department of Architecture on June 17, 1968 in partial fulfillment of the requirements for the degree of Master of Architecture.

This thesis aims at the development of a flexible, integrated, mechanical system adaptable to the rapidly changing needs, functions, and technology in the educational buildings.

This system study started as a 5'-0" x 5'-0" module system aimed at maximum flexibility of planning, each unit as a part of girder (major and minor types of girders) with inclined members acting as tension and compression members. But due to the complexity in its pre-casting and detailing which could increase the cost of the structure considerably, it was rejected.

The system presented is a two way double module, (3'-4", 6'-8") x (3'-4"x 6'-8"), resulting into 60'-0" x 60'-0" center bays and/or 60'-0" x 30'-0" has a cantilever of 15'-0" from the center of the column on all the sides of the bays.

The system is made up either 10'-0" x 10'-0" precast concrete units and/or bigger precast concrete units consisting of more than one 10'-0" x 10'-0" unit. The units used for the system which depended on various conditions of site, building size, etc.

The mechanical system involved has two basic variations, (though many more are possible), depending on the height of the building. In buildings of larger depth, up to six floors in height, a self-sufficient bay was designed with supply and return, both in columns and in higher and smaller buildings a self-sufficient floor was designed with supply in cores and return in the column.

Thesis Supervisor: Eduardo Catalana
Title: Professor of Architecture
ACKNOWLEDGEMENTS

To,

Professor Eduardo Catalano
Professor of Architecture, M.I.T.

Professor Y. Jung; M. Arch.,
Associate Professor of Architecture, M.I.T.

Professor Waclaw Zalewski; D. Tech. Sci.,
Professor of Structures, M.I.T.

Professor R. B. Newman; Sci. D.,
Associate Professor of Architecture, M.I.T.

Mr. C. Crawley; Mech. Eng.,
Boston, Massachusetts,

for their valuable assistance and encouragement during the development of the project.
1. INTRODUCTION

Today we live in a very dynamic society. Life as exhibited in communication, transportation, and education is changing at an extremely fast rate.

Because of this new set of ever changing conditions, human needs require a new approach to the consequent architectural problems. There is a demand for a functionally dynamic architecture. Due to economic and other practical reasons, it is impossible to make broad generalizations; there is no panacea for all architectural problems.

Therefore, for the purposes of this study, the following aims and assumptions serve as a starting point towards meeting these new architectural demands of a modern society.

2. AIMS

The study aims at developing an:
integrated
flexible
constructional
mechanical
electrical and
structural system to meet the ever changing needs and demands under various conditions.
3. ASSUMPTIONS AND LIMITATIONS

These limitations and assumptions are as follows:

1. The system will basically be used in India or other developing countries.

2. The system will be useful for offices, labs, and educational functions requiring a great many changes.

3. The system will not be used for housing (because of the economy), theatres, auditoriums, stadiums, arenas, for which either some changes or a completely different system will be developed.

4. The technique of construction will vary from cast-in place concrete, precast concrete and mixed cast-in place and precast concrete depending upon the local conditions.

5. The material of construction will be concrete.

6. The ceiling will be flushed for the reasons of standardized partition construction and maximum flexibility.

7. The building height will be limited because of the limitations due to the mechanical system.
8. The vertical, mechanical and other services will be in columns, and/or cores, depending on the particular situation.

4. CONCEPT

The most essential requirements of the flexibility in spatial planning and its potential to erect various positive and negative spaces i.e., to cover and enclose a space. The more important factor than anything else is the adaptability of the system to various conditions and therefore the economy involved.

The flexibility as a function of structure is a function of the unit of construction in precast construction. The unit should be of such dimensions that it can give more flexibility with regards to openings in the structure of various dimensions and the changes demanded later on without disturbing the structure. (Refer to Sketches). The smaller the unit, the more flexibility it will have to offer, but a small unit of construction will involve too much of manual labor as compared to larger units of construction.

In an industrialized society where mechanical equipments are available and labor is expensive larger units will be used and if labor is cheap and mechanical equipment is expensive smaller units will be used.

Since all kinds of conditions exist side by side the system developed shall be adaptable all the conditions however as already said the solutions presented to the condition in developing countries.
5. PLANNING MODULE

It is a double modular system (3'-4", 6'-8") x (3'-4", 6'-8") with 1:2 ratio between two modules. When the modular dimensions are added, the result is 10'-0". A 3'-4" module gives 3'-0" as a clear dimension. When bounded by 4" thick partition walls on the two sides, the 3'-0" dimension is the dimension of various building elements which are constant.

Three feet is the width of the W.C., the usual size of a door opening, the minimum width of a stairway, the minimum width of a private inner office hallway and also relates to many standard furniture dimensions and other fittings, etc.

6. THE STRUCTURAL SYSTEM LINEAR OR NONLINEAR

The choice of a structural system will usually depend on the site conditions and possible directions of growth. The Linear system will be ideally suited for a linear site while a squarish site will give the possibility of a bi-dimensional growth and therefore a two way or a non linear system will be idea.

While designing a system regardless of any particular site a two way system will be the solution thereby giving possibility of flexibility and growth in both the directions and therefore more universally acceptable than a oneway or linear system.
7. THE STRUCTURAL BAY 60'-0" x 60'-0"

The basic considerations in deciding the bay size are that almost all the required spaces could be formed without any kind of special construction otherwise the system will not be valid at all.

It seems that a 45'-0" width will normally meet all the requirements of an educational building while anything above 45 feet will provide with more flexibility in planning and besides this will provide for a hall way within the bay in both the directions.

The bay size that has been accepted is 60'-0" x 60'-0" centers. Parking was one of the important factors in selecting a 60'-0" x 60'-0" bay. 60'-0" width is used for parking at right angles provides for two stalls 19'-0" deep and 22'-0" wide driveway. Six cars can be parked between two columns and the minimum dimension 56'-8" provides enough space for variations of column sizes if any. Many other parking arrangements are also available in this width.

The structural depth of 3'-6" has been accepted (excluding flooring) which gives enough space in the form of openings in the floor for all mechanical and plumbing equipment for a self-sufficient bay.

The span to depth ratio is 17 (60'-0"/3'-6") which lies within the economic range.
8. THE CONSTRUCTION TECHNIQUE

Precast concrete construction system was the only one considered and in fact this was the beginning point of the system.

The precast concrete has several advantages over steel and cast-in-place concrete construction.

Precast concrete is fire proof by itself. Precast concrete system provides for better quality controls and therefore has higher ultimate stresses than the cast-in-place concrete construction. Precast concrete construction work is not hampered due to unfavorable weather conditions.

Precast concrete plants can be installed at the sites of construction of big projects without any loss of economy.

9. THE SYSTEM

The system presented is a two way system composed of a double modular system of (3'-4", 6'-8") resulting into a 60'-0" x 60'-0" bays. The system is also capable of being adapted to double bay systems of (30'-0" x 60'-0") and 30'-0" x 30'-0") which although is uneconomical offers the possibilities of a more flexible pattern of growth (refer to drawing no. 2.)

The structural system is capable of providing conditions of various dimensions up to a maximum of 25'-0"
from the center of the column. The various cantilevers can be 8'-4", 11'-4", 15'-0", 18'-4", 21'-8", and 25'-0" on all the four sides of 60'-0" x 60'-0" bay. The various cantilevers also simplify the possibility of opening possibilities i.e. enclosing a space of various dimensions.

The partition can be placed at alternating dimensions of 3'-4", 6'-8". The smallest usable area and therefore the smallest area served by mechanical services is 10'-0" x 10'-0". The various possible enclosures can be of any dimension from 10'-0" plus an increment multiple of 3'-4". The partition layout can be designed to meet most of the space requirements without jumping to large dimensions for the next grid.

The two way system provides the possibility of bi-dimensional extension and therefore suited to any kind of site location.

10. SYSTEM COMPONENTS

The system is composed of the following components.

10.1 Building System
10.2 Mechanical System
10.3 Piping System
10.4 Electrical System
10.5 Acoustical System

10.1 Building System:

Building system is composed of the following components.

Column
Column Key
Column Capital
System Units
  I. Column Strip Units
  II. Infill Units and Slab.

The column is composed of four precast L shaped units 3'-4" x 3'-4" x 8" thick x 10'-0" height. The form of the column units helps in very easy stacking at site, storage and during transportation. (See photographs). The column has been designed to accommodate within itself vertical mechanical and other systems for self-sufficient bay in various manners, explained in the sketches. The L-shaped columns are joined at regular intervals to give stiffness to the column, so that is should act as a monolithic column.

The column key is a precast unit of 10'-0" x 10'-0" x 8" thick x 1'-0" height of shaped, which is placed over the column for 50% of post tensioning of the units.

The column capital is composed of four cast-in situ L shaped units of 3'-4" x 3'-4" x 8" thick x 2'-9" in height tapering upwards to abut against the column strip units. The reinforcement of the column strip units has been taken into this cast-in situ column capital to make the whole structure as a homogeneous one. (See photographs.)

System units are 10'-0" x 10'-0" precast units in overall dimensions composed of four ribs of (10'-0" x 10'-0" at the bottom and 8'-0" x 8'-0" at the top) x 3'-6" deep with two ribs at 3'-4" centers intersecting the other two ribs also at 3'-4". Centers as shown in
the sketch. The thickness of the ribs varies depending on whether the units are column units or infill units. The rib thickness in case of column units is 8" and 5" in case of infill units.

The slab units are 10'-0" square 3" thick precast concrete.

10.2 MECHANICAL SYSTEM:

The units when placed together to form the system give a double modular system of (3'-4" x 6'-8") x (3'-4" x 6'-8") with openings in both directions along the 3'-4" modules for horizontal mechanical system.

In deep buildings up to 6 floors in height, a self-sufficient bay is designed with supply in cases and return in columns because the columns will become very thick and space in columns will not be enough to accommodate all the ducts.

High velocity (4000 fpm) supply single ducts and low velocity (1200 fpm) return duct along the plumbing electrical system run along the space between the four columns. The vertical air supply has a maximum velocity of 4000 fpm and this at the juncture with the slab is reduced to 1200 fpm in velocity by means of control value and then passed through an attenuator system combined with a reheat unit where applicable, thus reducing the noise. This supply air at 1200 fpm is finally reduced to 700 fpm at the point of supply. Eighty percent of the supplied air is then returned to the column as a maximum velocity of 1200 fpm. At the column this may be increased to approximately 1,850 fpm. The main distribution lines run between the column units and branch out to serve the individual spaces.
The various possible variations are shown in the sketches.

10.3 PIPING SYSTEM

Piped services including plumbing, roof drains, hot and cold water, supply and return for random, sinks, and reheat, recool coils of the perimeter air system. These services rise within the column and are distributed throughout the 3'-4" service module in the horizontal plane.

10.4 ELECTRICAL SYSTEM

The electrical system like mechanical system will also be in columns and cores vertically and horizontally along 3'-4" module for illumination with underfloor duct or conduit embeded in floor for typewriters and other appliances with outlets at every 10'-0".

10.5 ACOUSTICAL SYSTEM

The resulting ceiling pattern is composed of 6'-8" square waffle with solid ribs on all sides, 6'-8" x 3'-4" waffle with openings on 3'-4" wide ends and 3'-4" squares waffle with openings on all the four ribs. The 6'-8" square waffle presents no sound leakage problem and 6'-8" x 3'-4" and 3'-4" square waffles can be taken care of by suspended ceiling in both cases leaving 6" deep waffle visually which architecturally will be acceptable because of comparatively small size as compared to 6'-8" square waffles which is 3'-6" deep. See sketch.
12. STRUCTURE

Structurally, the system can be explained to be composed of series of 60'-0" x 60'-0" bays. Each bay is composed of two way structural system resulting into a waffle slab of 6'-8" square 3'-4" x 6'-8" and 3'-4" squares and 3'-6" deep. The units which span directly between columns are column strip units and others are infill units. All the fabricated units are placed on form work by manual labor and minor mechanical equipment in respective position.

The post tensioning cables are placed in position and are tensioned (50% post tensioning before the joints are cast and 50% after the joints are cured) in both directions. The joints are cast, resulting into a waffle slab and thus the system.

Prefabricated slabs of 10'-0" x 10'-0" x 3" thick, are the part of the structure. These are placed on the waffle slab grid. These slabs contain the necessary circular openings temporarily blocked by wood or concrete "corks" to accommodate piping connections to 3'-4" wide shafts below. 2" topping is cast over the whole area, leveling the floor to protect surface tension bars, and to house the electrical and telephone communication system where needed.

12.1 SYSTEM UNIT, PRECAST ELEMENTS, CONSTRUCTION SYSTEM ELEMENTS, VARIABLES.

The unit of construction described under the heading "Building System" is the smallest possible unit and number of such units assembled together by cables will
form the system. This will involve certain amounts of form work (which is applicable in developing countries where large equipments are not available) which will be too much for a large building in an advanced country, equipped with larger mechanical equipments. To reduce the form work, the units could be adopted in many ways to achieve the system. The adaptations or variables will depend very much on:

1. Depth of the building related to carrying capacity of the same as a factor of distance of carrying.

2. Cost of labor compared to the cost of mechanical equipment.

3. Location of the factory.

When the condition will be favorable the precast units shall be bigger in size composed of 3, 4, 5 and 9 units. (See sketches). This will not only save lot of form work but also reduce:

1. The number of joints
2. The number of crane operations
3. The number of post tensioning cables
4. The number of crane operating positions

and thereby help to achieve economy. The units are used with three variations in the three zones of the bay:

1. Capital zone
2. column zone between capitals
3. Infill zone (See sketches)
The use of bigger units also help to develop a system of construction which has the advantage of a two way system and simplicity of the one way system.

The only other building element is the column which is also a precast unit.

12.2 BUILDING ELEMENTS:

The major building elements are elevators and stairs for vertical circulation, corridors for horizontal circulation, toilets and shafts for mechanical system. The elevators and stairs are the means of vertical circulation are grouped with toilets and mechanical shafts to form building cores.

The number of elevators and sizes of stairs is depended on the code requirements. The width of the corridor depends on the function and the load of area surrounding it.

13. ERECTION PROCEDURE

The erection procedure will vary depending on the size of the precast units used, the length, the depth and the height of the buildings.

Though these are numerous variations in the erection procedure, the three described below are the most significant.

13.1 VARIATION A

The unit of construction is the smallest possible unit of 10'-0" x 10'-0" dimension. The buildings are
low and deep. The steps of erection involved are the following:

1. The foundations are cast.
2. The columns are placed and tack welded to the foundations.
3. Form work is erected along the line of columns.
4. Column key is placed and tack welded to the column.
5. Joints are grouted.
6. The precast column strip units are placed in position.
7. Form work erected in space enclosed by these units.
8. The precast infill units are placed in position.
9. 50% post tensioning of the column units.
10. Casting of the joints.
11. 50% post tensioning of the infill units in both directions.
12. Casting the joints.
13. 100% post tensioning of the column units.
14. 100% post tensioning of the infill units.
15. Placing of the slabs.
16. Welding of the bars from the units to the slab bars.
17. Grouting of the slab joints.
18. 2" topping poured.

The structure now is completed. Additional steps involve placement of mechanical equipments.
13.2 VARIATION B.

The units of construction are precast to the size of 3 or 5 smallest units of 10'-0" x 10'-0".

The capital units are 30'-0" x 10'-0" or 30'-0" x 30'-0", columns units are 50'-0" x 10'-0" or 30'-0" x 10'-0" and infill units are 50'-0" x 10'-0". Buildings are low in height, long and narrow. The steps of erection involved are the following:

1. The foundations are cast.
2. The columns are placed and tack welded to the foundation along the full length of the building.
3. The form work is erected.
4. The capital units are placed in position.
5. The column units are placed and tack welded to the capital pieces along the length of the building.
6. All the joints are grouted.
7. The post tensioning cables are placed along the building length and tensioned.
8. The column units and infill units are placed along the depth, tack welded to column units and to the capital units.
9. All the joints are grouted.
10. Slab units are placed.
11. Welding of the bars from the units to the slab bars.
13. Reinforcement for topping and post tensioning cables are placed.
14. Concrete topping is poured
15. The cables are post tensioned.

13.3 VARIATION C

The units of construction are precast to sizes of 3 and 9 smallest units of 10'-0" x 10'-0". The capital units are 30'-0" x 30'-0", column units are 30'-0" x 30'-0" or 10'-0" x 30'-0" and the infill units are 30'-0" x 30'-0" or 10'-0" x 30'-0". The buildings are small and high. The steps of erection involved are the following:

1. The foundations are cast.
2. The columns are placed and tack welded to the foundations.
3. Form work is erected.
4. The capital units are placed in position.
5. The column units are placed and tack welded to the capital units in both directions.
6. All the joints are grouted.
7. The post tensioning cables are placed in both directions and tensioned.
8. The infill units are placed in position and tack welded to a column unit.
9. All joints are grouted.
10. Slab units are placed.
11. Welding of the bars from the units to the slab bars.
13. Reinforcement for topping and post tensioning cables are placed.
14. Concrete topping is poured.
15. The cables are post tensioned.
CORE ELEMENTS AND CORE VARIATIONS

MASTER OF ARCHITECTURE
FALL 1967
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
JITENDRA KUMAR MADAN