BUILDINGS AS INTEGRATED SYSTEMS

by

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Bachelor of Architecture (with Distinction)
University of Minnesota
(1966)

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

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1967

Signature of Author

Department of Architecture, June 1967

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10 June 1967

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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 "Buildings as Integrated Systems."

Respectfully,

William F. Burch
ACKNOWLEDGMENTS

To Professor Eduardo Catalano and to Professor Waclaw Zalewski for their valuable assistance and encouragement during the development of this project.
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"...SOONER OR LATER, THE SOFT UNDERBELLY
OF ARCHITECTURE, THE HUNG CEILING, HAS
TO YIELD ITS PLACE TO STRUCTURE INTEGRATED
WITH ARCHITECTURE."

—Aldo Cossutta
1 Description

The structural system, based on a bay size of forty feet by sixty feet, is composed of double tee members which span the long dimension and composit girder members which span the shorter distance. Columns and girders are split to accept the mechanical system.

The wholly precast system is composed of three basic units. Simple span double tee filler units, forty feet long, span between cantilevered girder-tee units on each side. These cantilevered tees are cast monolithically with five foot girder sections which are post tensioned together to form a final girder unit. Compression pieces are placed between the split girder elements, and mechanical access openings are provided which lead into the double tee. Up to a twenty foot tee cantilever could be added to either side of the girder if so desired. The third unit is the column. The particular column design chosen attempts to define bearing and non-bearing areas within the column, the non-bearing areas appearing as flanges whose function is to shield end portions of the vertical mechanical space. Precast in lengths of two to three stories, the column is slotted to accept the girder elements. Since the continuity of the column limits the bearing area available for the girder, one set of post tension cables is brought up into the column to increase its bearing potential.
Four sets of post tensioning cables are utilized. Two of these run continuously along the top and bottom of the girder. The other two sets are discontinuous, one running above the bearing area of the column, anchored through mechanical openings in the girder, the other running on the bottom and then up through the girder, across through the column, and then anchored.

2 Base Decisions

a Bay Size

There are four criteria involved in the basic choice of a bay size. Structural efficiency, mechanical efficiency, system flexibility, and space requirements for the storage and circulation of automobiles.

General criteria for the choice of larger spans, those spans in excess of thirty feet, is that larger spans offer greater planning flexibility. Also, since there is a certain unavoidable depth taken up by the placement of pipes and ducts in the system, this depth should relate to an efficient span distance.

From these basic criteria, a bay size of forty to sixty feet seemed reasonable. Both of these dimensions are adequate for handling automobile storage. Both spans are commensurate with a three foot clear depth necessitated by the mechanical and plumbing systems.

The basic core size, dependent upon the void possibilities within the span and upon the size of the core components,
was found to be about forty by fifty feet. This core would include toilets, fire exits, and elevators for an eight bay area. In a sixty foot span, therefore, a forty foot wide core may be placed leaving a ten foot circulation path on either side of the core.

To gain maximum flexibility the long dimension of the bay was spanned with the secondary structural member. A more conservative span, in the area of forty feet, was chosen for the major structural member based on efficient run of mechanical services and the desired depth of the member itself.

b Double Tee System

It was assumed from the outset that a variation of the commonly produced precast tee sections would be the most economical choice for the secondary structural members spanning the long direction. These units offer a composite floor and joist member and hence reduce the quantity of precast pieces needed, and also gain greater structural efficiency by allowing the floor slab to act in compression.

Of the typical precast members, the double tee and channel units seemed to offer the greatest possibility in terms of mechanical integration. With these members a double spacing or double module can be set up whereby a large-small-large-small ceiling rhythm is produced. The small module becomes useful for placement of pipes and ducts, while the large module can be utilized for the placement of luminaries.
Channel members were chosen in the earlier schemes due to the ease of casting transverse diaphragms integrally with the member. The channel member was later replaced by a double tee unit, which simplified post tensioning of the girder members, rendering the transverse diaphragms as separate precast, or poured in place, units.

c  Cantilever in Secondary Direction

To gain the greatest amount of flexibility possible, a cantilever in the secondary direction, beyond the girder, would be desirable. In order to achieve this cantilever with maximum continuity in the double tee members, the double tee members were designed with sections of the girder cast integrally with them. A typical girder member, then, would be composed of a five foot length of the split girder with ten foot lengths of the double tee attached on either side in a perpendicular direction to the girder. The girder sections, with the tee units on either side, could then be post tensioned together to form the desired girder length. In each of the girder segments, an opening was provided to service the small module of the double tee system from the main mechanical trunks within the double girder. In earlier schemes, where channels were used as the secondary spanning member, this hole interrupted the bearing surface on either end of the girder segments producing a less than ideal post tensioning situation. Consequently the channel members were changed to double tee units, which had the effect of positioning the opening in
the center of the girder segments, leaving the bearing surface uninterrupted.

Unlike the filler tee in simple span, the cantilevered portion of the double tee unit is required to take compression in the flange area. For this reason the flange section was increased from the filler tee bearing area to the girder, becoming larger as it approached the girder.

Because the change from channels to double tees inhibited casting the transverse diaphragms monolithically, provisions were made in the double tee units to pour the diaphragms in place. Slab widths of the double tees were reduced by one foot providing a one foot opening between each tee through which the diaphragms could be poured. These one foot strip openings would be closed by a light, fire proof, sound absorbing, form work before placement of the topping.

B MECHANICAL SYSTEM

1 Mechanical Description

The mechanical system chosen is a single duct reheat system utilizing columns for vertical supply, return, and pipe chases. Main horizontal runs for all systems occur between the split girders and branch out through the girders into the small module of the double tee system.

Alternate small module spacings in the tees are used for piping. The remaining small module spacings are used for a system of supply ducts and return plenums. The supply duct within the tee branches out through the tee in both directions
to feed light fixture-diffusers located high in the large module spacings. Return air is picked up at the bottom of the small module spacing, beneath the supply duct, and is sent through a plenum to the main return duct between the girders.

All air being supplied to the module and returned from it is low velocity, low pressure, based on a friction coefficient of .07. All air traveling within the girder travels at 1500 FPM. The return air continues vertically at this speed, whereas the supply air travels vertically at 5,000 FPM before encountering attenuation boxes at each floor level, reducing it to low velocity.

2 Base Decisions

a Column Supply

There are several advantages to the column supply system, over the core supply system. Column supply is the more integrated of the two, as wherever the system is, or wherever it expands, vertical mechanical supply will be provided. Another basic advantage of column supply is the placement of vertical air shafts in comparably close proximity to diffusers and return air pickups. Consequently, the quantity and size of ducts can be reduced from that required for core supply.

A pattern of vertical supply and return was chosen whereby supply, with its attenuation boxes, was located at every other column in either direction, alternating with the columns used for both return air and vertical pipe chases.
b Single Duct Reheat

The single duct reheat system, compact in itself, becomes highly flexible with the use of electric reheat coils. In this system supply air can be reheated at a variety of locations depending upon the size of the zone required. The coils can be inserted at the attenuation box, the juncture of the horizontal branch ducts with the major trunks, or at any light fixture-diffuser, each location affecting a progressively smaller area, and providing at the same time a more flexible system.

C ADDITIONAL DESIGN CONSIDERATIONS

1 Core Design

Cores were designed based on void possibilities within the structure, probable circulation paths, and vertical circulation needs of varying floor areas. Basic components such as fire stairs, freight and passenger elevators, and men's and women's toilets were dimensioned to either stand alone within the structure, or combine and form a larger more complex core.

Major cores were designed to serve a net floor area of 24,000 square feet. Maximum clear core spacing under this condition would be 120 feet in the girder direction and 154 feet in the direction of the tees.

Mechanical services carried by the cores relate only to the needs of each core, independent from the mechanical needs of the rest of the building.
2 Acoustical Considerations

In a flexible system the great problem is to obtain a sufficient amount of sound isolation between adjoining spaces. There is no one simple way to accomplish this. Sound can be stopped by either vertical or horizontal elements, by proper diffuser spacing, by lining ducts and by gasketing all joints which are not air tight.

All of these procedures would be employed in this system. Vertical sound barriers, meeting the walls, would consist of the flanges of the tees and the transverse diaphragm units. Horizontal barriers would be of metal panels beneath the return plenum areas, and the concrete slab itself. Air supply would be located at the center of each module for maximum sound attenuation between diffusers. Return ports would be staggered producing a similar effect. Where the supply duct branches two ways to the light fixture-diffuser, a baffle would be inserted within the duct to block direct cross duct sound paths.

Two basic sound absorptive areas are provided. The metal panels at the bottom of the small module can be treated with sound absorptive material, as can the area above the luminaries in the large module. Treatment such as this would provide for a forty per cent coverage of the ceiling with acoustic material.

D CONSTRUCTION SEQUENCE

Foundations for columns poured
Columns erected and tied to footings
Scaffolding erected for girder members
Girder members placed on scaffolding
Post tensioning cables sent through girder units
Bearing surfaces grouted
Girder post tensioned
Post tensioning cables pressure grouted
Filler tees positioned and welded to girder units
Transverse diaphragms poured
Topping poured

E MODEL TECHNIQUE

The model describing the proposed system was cast in plaster with the use of plexiglass form work. The form work was constructed in such a way that it could be removed from the casting with limited shearing motion, which could cause breakage.

To create the volume of the small module of the double tee form work was surrounded on three sides by the casting. The form for this area was constructed of three pieces, a top and two side pieces. These three pieces were joined flexibly to enable the sides to pull away from the casting. Breaking the bond between form and casting simplified removal of the form work. This basic principle of breaking bond before attempting removal of form work was employed consistently.

In the girder and column forms, locating holes were provided for the placement of piano wire, which produced the openings for post tensioning cables in each casting.
Girder units with twenty foot cantilever on one side were cast by abutting the girder form with the filler tee form and allowing plaster to fill the girder form completely flowing into as much of the tee form as required.

Brass wire was used for the post tensioning procedure. The wire was hand threaded at each end with an 0-80 die. After the wire had been threaded through the structural members, nuts and washers were added at either end. The nuts were then tightened producing adequate tension.

Several phenomenon in post tensioning the model were noticed which have relation to actual post tensioning procedures.

When a large number of pieces are to be joined by post tensioning, the bearing surfaces must meet in a near perfect manner. A very small mistake on each piece will be multiplied many times by the tensioning process. The ultimate size of each member is also extremely important as a variance in length will cause an overall variance in bay size.
MECHANICAL AND STRUCTURAL DETAILS
STRUCTURAL BAY SECTION VARIATIONS
FROM SYSTEM TO UNIVERSITY

One of the criteria for the design of the integrated building system was that it should be most easily applied to the construction of a university complex in an urban situation. Consequently, the system was designed to accept office spaces, classroom and laboratory spaces, as well as parking areas. It was not designed to accept functions which have spatial requirements that dictate either very short or very long spans, therefore, residential units and large sports facilities fall outside of the basic system, and must be designed as independent structures.

Although these particular functions do not use the building system, a variety of other facilities were easily integrated into it. Major lecture rooms, requiring sloping floors, were incorporated into the system by adding non-system diagonal structural members to a basic double tee void. A small theatre was included without any changes or additions to the basic system. The removal of one column made it possible to integrate an auditorium into the system, creating a void area in the construction above this function.

For a project of this size, the building system was not a strong design limitation. Had it been a strong limiting factor, it, by itself, might have determined the form and quality of the university project. However, due to the system flexibility, other factors such as site and building program were relied upon for design limitations. Due to the abstract quality of these two limiting factors, the university project itself became abstract and was basically an exercise in exploiting an integrated building system.
II THE URBAN UNIVERSITY

A THE CITY

The site for the university is within a city of an assumed population of over two million. The city is involved in urban renewal programs and has several underway in the vicinity of its core area. The university has elected to develop one of these renewal sites for a new campus. The new campus is not to be isolated from the city, but rather will attempt to become an integral part of it. It will begin this integration slowly by replacing a small disintegrated area near the most dense part of the city with a new vital center for learning. This center will invite community interaction and provide community as well as campus oriented facilities.

B THE SITE

The campus site, on land gently sloping from north to south, is eight blocks from the main core area of the city. The site was filled with structures not uncommonly found in the core fringe area of a large city, that is, a mixture of run down and generally unmaintained residential, commercial and light industrial buildings.

To the east of the site lies the core of the city and, consequently, the east-west roads in the area generally carry a good deal of traffic. Commercial fingers run from the core toward the site, but only one is of any major importance, having managed to acquire a few new office and commercial structures. This street then, the strongest commercial finger extending west
from the core, will be considered an ultimate northern boundary to the site.

On the north of Commercial Street the neighborhood is a mixture of small office buildings and an occasional spattering of speculative high-rise apartment buildings. Because of its desirable location, on a hill top in close proximity to the core area, the neighborhood is beginning to renew itself as a high density residential area.

The neighborhood south of Commercial Street, in the heart of the renewal area, is the site on which the campus will be centered. Continuing south the neighborhood begins losing light industrial functions and becomes solid residential, four and five story walk ups predominating. Many of the buildings are rundown, but of basically sturdy construction, and it is felt that a good many can be repaired and generally cleaned up. Consequently in this neighborhood a spot renewal program will be initiated and administered by the university.

Further south, the residential quality continues to improve and it is in this area that a major east-west residential parkway occurs.

C THE CONCEPTION

The governing concept of the university complex was to create a major space within the texture of the city which would integrate university and community life. On its lowest levels this space is designed to contain great amounts of activity. To insure
this activity it was necessary to introduce elements, relating to the space, which in themselves produce activity and elements which tend to support and sustain existing activity.

The first of these elements is that of circulation. Four major community oriented pedestrian routes pass into the space. The north route, already fed by automobile drop off, is also related to a major bus stop on Commercial Street. The route to the south orients to the residential community and it is a major feed for those persons attending theater or auditorium performances. The route to the east forms a bridge across the major north-south artery, which previously separated the campus from the core area of the city, tying a student high rise dorm complex to the major space. In the first stage of the campus, the route to the west ends at an automobile drop off. As the campus grows this route will be extended to serve an additional high rise dorm complex.

In addition to these strong pedestrian arteries, a subway station is provided below and within easy reach of the space itself.

A second method of intensifying activity in the space itself, is to focus potentially active university functions around this space. Such usual student center functions as dining, commercial and lounge facilities, would surround this center of activity. In addition, the theater and auditorium would be placed in close proximity to this major space.
In addition to the active functions surrounding the major space, the base of the complex also contains other less active, though non-academic, functions. The administrative functions, the gallery, and the health and athletic facilities all are in this category, and are located peripherally on the site in order to be reached easily and directly by pedestrian traffic.

The non-active or academic functions also surround the major space, but are vertically separated from its activity. The space, then, is a common orientation point visually relating the academic and the social functions.

Placed as a vertical bridge between the active base area and the upper academic structure, the library becomes a dominant element in the complex. It is accessible from nearly all levels, and forms a major interior space at the north entrance to the complex.

D CIRCULATION

1 Pedestrian Circulation

Pedestrian circulation can be explained in terms of a three dimensional grid system. The horizontal grid is made up of a major and minor axis. The major axes run east and west and the cores, or points of vertical circulation, are regularly placed along them. The minor axes also extend from the cores, but in a north-south direction. Core placement in this direction varies due to changing
circulation needs. The cores, the vertical portion of the circulation grid, are split to enable uninterrupted pedestrian flow to pass through them.

2 Automobile Circulation

Automobile routes and parking areas are spatially and visually cut off from the campus above due to the problems of noise and exhaust fumes. These parking levels run continuously beneath the site, giving automobiles and service vehicles total access to the various areas of the complex. Entering from one of four areas, each area containing surface parking, vehicular traffic circulates in a one way counter-clockwise rotation on an interior ring road. Cores may be approached directly from this road by service vehicles, and minor roads, leading to parking spaces, intersect the ring road at various intervals. Parking for the married student complex occurs on the south side of these levels, and is served by a separate but related exterior road.

E GROWTH

The campus, as it grows, will attempt to maintain the land use functions it begins to replace. Consequently, on the south or residential side of the complex, married student housing has been established to maintain the residential quality of this neighborhood. As the housing expands south existing structures will be maintained if possible and integrated with new construction where necessary. Linkages from these expansion areas will be made to the existing complex.
Growth on the north and west sides of the campus will occur in predominantly commercial areas. To insure consistent commercial activity in this area the lower portion or base of the complex will form commercial space, with academic functions carried above.

As the academic structure expands away from the center of gravity, it will begin to form secondary exterior spaces, surrounded by academic functions above and containing speculative commercial space below. These new minor spaces will be subservient to and relate to the existing major space.