

SYSTEMS OF URBAN GROWTH

by

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Dear Sir:

I submit this thesis, Systems of Urban Growth, in partial fulfillment of a Bachelor's Degree in Architecture.

Sincerely yours,

Nicholas Negroponte

Signed by: Lawrence B. Anderson  
Dean of the Department of Architecture

## ACKNOWLEDGEMENTS

It is customary to acknowledge all those that have contributed to the fulfillment of one's work. I do not forget the debt I owe to a similar list of people. Yet, it is my intent here, to thank the two people who have done more than contribute; have actually guided me through the soul-searching and learning process this thesis has lead me.

First, Professor Imre Halasz, of the Department of Architecture at M. I. T., whose criticisms have been an education and whose teachings have provided for me a true set of values. Secondly, Mr. Leon Groisser, a structural consultant for the M. I. T. Department of Architecture, who, far beyond the realm of engineering, has donated philosophy and enthusiasm, vital in moments of disenchantment.

## PREFACE

Inherent in the nature of research is a constant change in end as a result of a continuous change in means. At the beginning of this thesis I had all the answers, now at the end I have almost none. Half of the thesis was spent in finding the questions by choosing points of reference in urban context, stimulated for the most part by a rather naive intuition.

Transportation was the first serious point of departure, from which I studied the city. This was done in conjunction with the Masters' class and their study of High Speed Ground Transportation. This point of reference permitted me to understand the city as an organism -- a machine of communication -- but did not seem to have the question for which I was looking. However, the relationship of speed to land use provided a natural second point of reference; density. This was the beginning of questioning the city as a volume. Unfortunately, in present statistics, density is a two dimensional phenomenon; though it was from here that I was able to find a last vantage point from which I could confidently ask one question.

This last point of reference was population, generating a study of how populations live, what populations want, and primarily, how populations expand. It was from the study of

how populations increase, that I arrived at the questions with which this thesis will endeavour to deal -- GROWTH.

This thesis has little need of preface, for indeed, it is "all preface, "

Boston, Massachusetts

September, 1965

N. D. N.

## TABLE OF CONTENTS

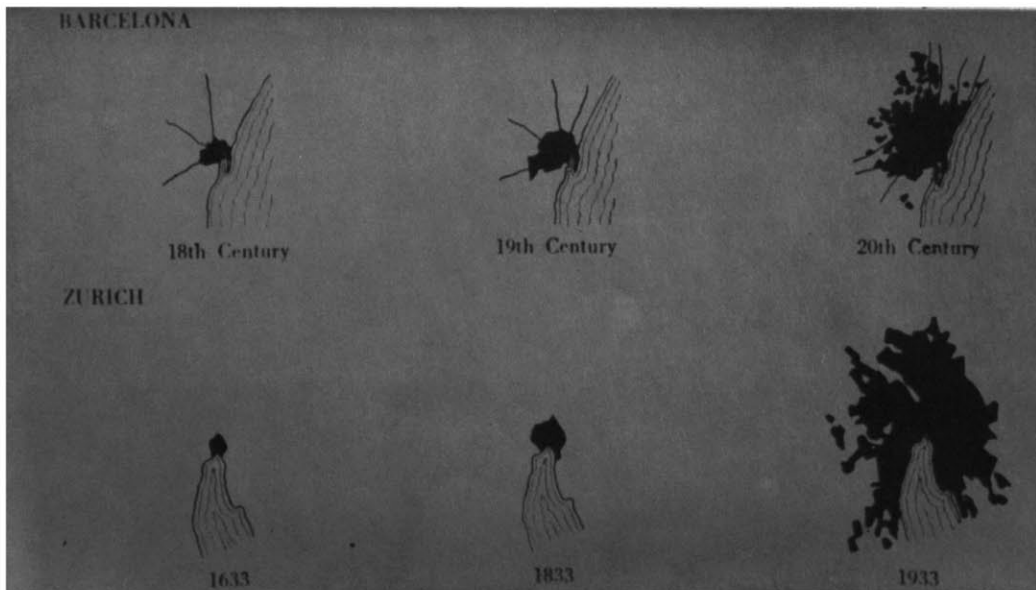
	Page
INTRODUCTION . . . . .	1
CHAPTER ONE: The Quantitative Framework . . . . .	3
Population . . . . .	4
Energy . . . . .	8
Mechanization, Transportation, and Communication . .	13
CHAPTER TWO: The Physical Response . . . . .	20
Growth . . . . .	21
Size . . . . .	26
The Parts . . . . .	31
Dimensions . . . . .	34
Geometrics . . . . .	37
Sociological Forces . . . . .	40
CHAPTER THREE: Systems . . . . .	44
Symmetrical Systems . . . . .	45
Linear Systems . . . . .	47
Patterns . . . . .	52
Scales and Series . . . . .	55
The Third Dimension . . . . .	63
Growth . . . . .	68
CHAPTER FOUR: Mechanics . . . . .	70
Introduction . . . . .	71
Urban Piano Nobile . . . . .	72

	page
Three Dimensional Mova-grid . . . . .	74
The Mega-grid . . . . .	76
Mechanical Grid . . . . .	78
Structural Components . . . . .	81
The Jacking Process . . . . .	85
Next Stages . . . . .	87
BIBLIOGRAPHY . . . . .	96

## INTRODUCTION

The very idea of "growth" generally has happy connotations: "bigger" has semantic associations with "better." In all societies, birth is normally "a blessed event," whereas, death is tragic. Therefore, a positive evaluation of procreation and population growth is deeply rooted in the traditions of most societies. This is translated into planning schemes and labeled as "expansion," in the short range, and "growth" in the long range. Growth usually pertaining to an organic process, provides a logical nomenclature, as expansion excludes any Darwinism.

Traditionally, this attitude toward population increase was suitable and did permit cities to grow organically over a long period of time. The translation of expansion to growth was a tearing down and building up process that was for the most part in phase with the age of urban units.



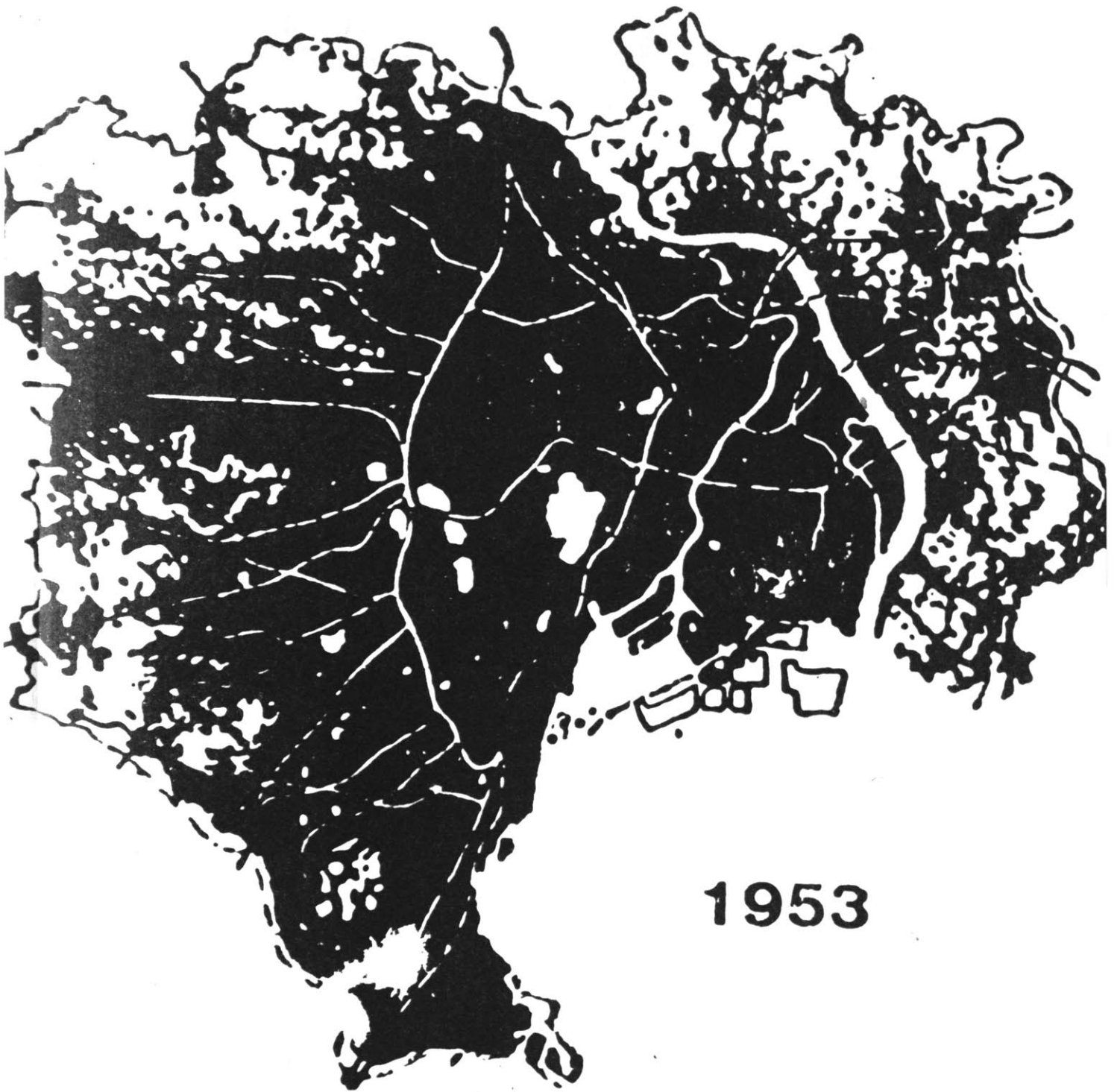


In the Seventeenth and Eighteenth centuries, it would have taken the world population about 800 years to double, whereas, today we are doing it in less than forty years.<sup>1</sup> Therefore, it seems logical that the growth process in our present urban environment cannot work as "destruction-construction" phenomenon, but must work as an organized system that can grow and change. Unhappily, we do not have a precedent at which to look, as this is a new environmental condition. Through technology, man has substantially reduced natural checks and now faces either the potentials or consequences of his own achievement. The present era is unique in that a predominance of man is being established in the earthly environment such as never before existed. We are in the midst of an ecological revolution; this revolution is as irreversible as the leveling of mountains by wind and rain.<sup>2</sup>

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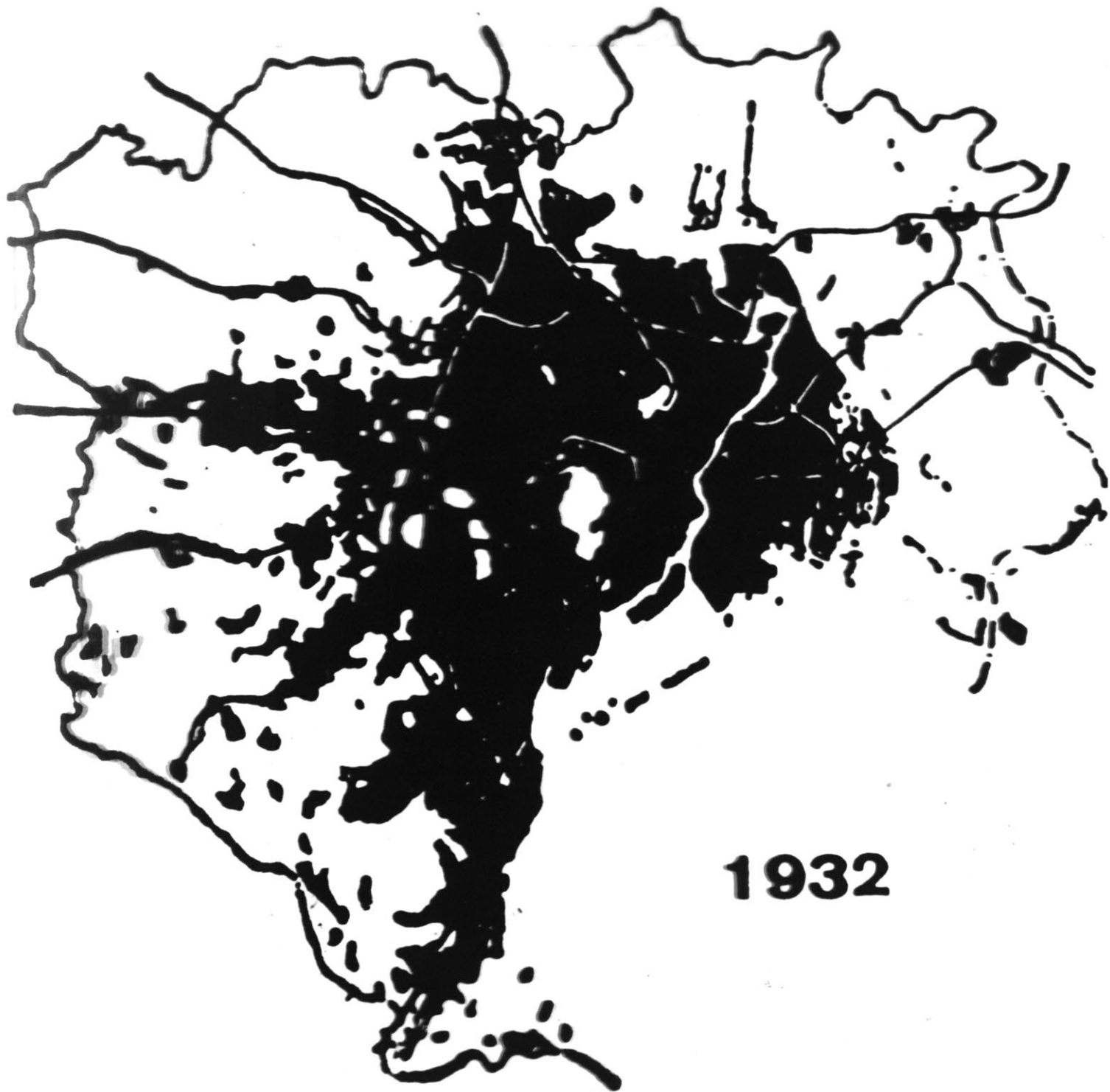
<sup>1</sup> Annabelle Desmond, "How Many People Have Ever Lived on Earth," Population Bulletin, 1962.

<sup>2</sup> Harold J. Barnett, "Population Change and Resources: Malthusianism and Conservatism," Demography and Economic Changes in Developed Countries, Princeton, 1960.

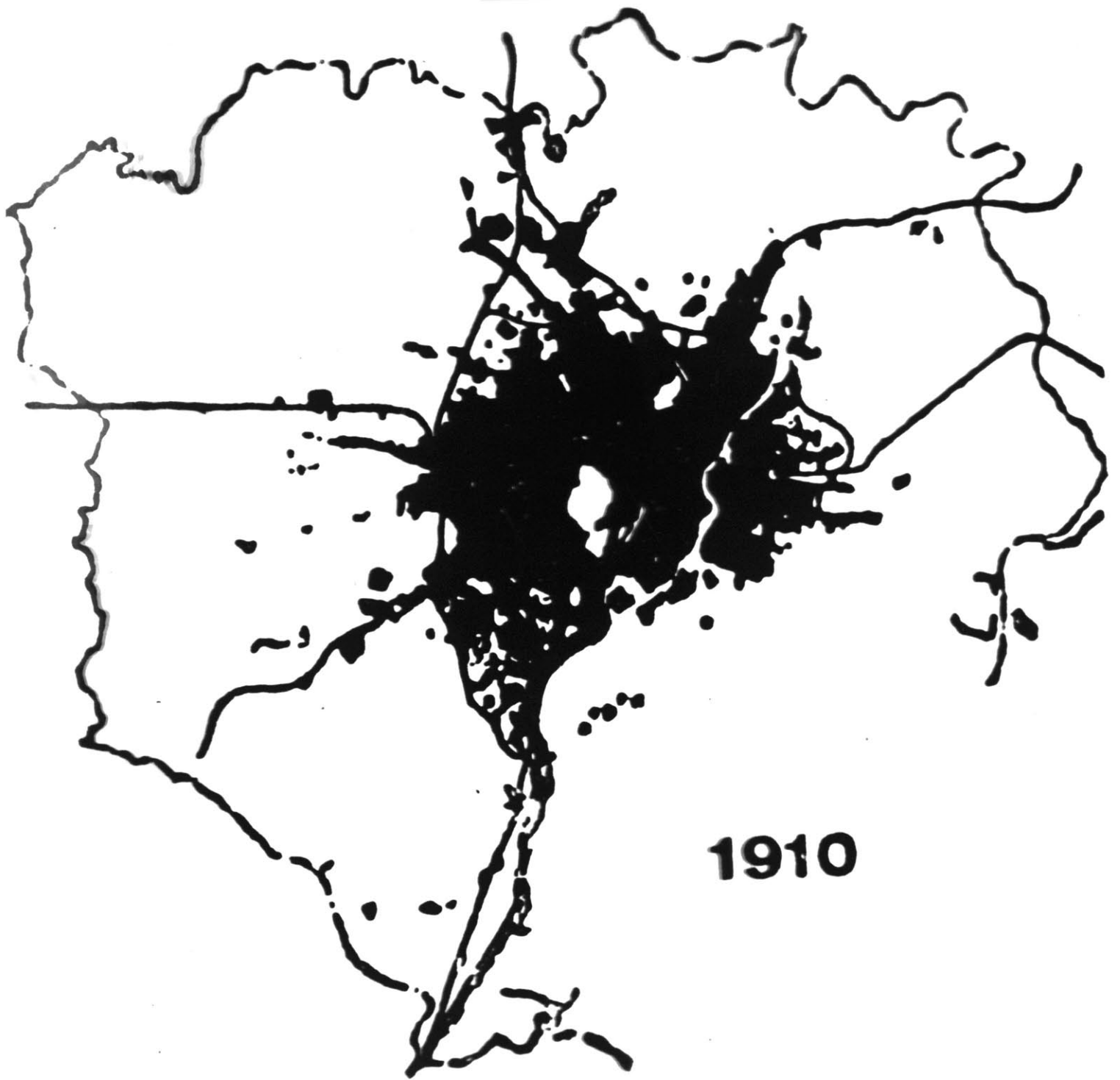


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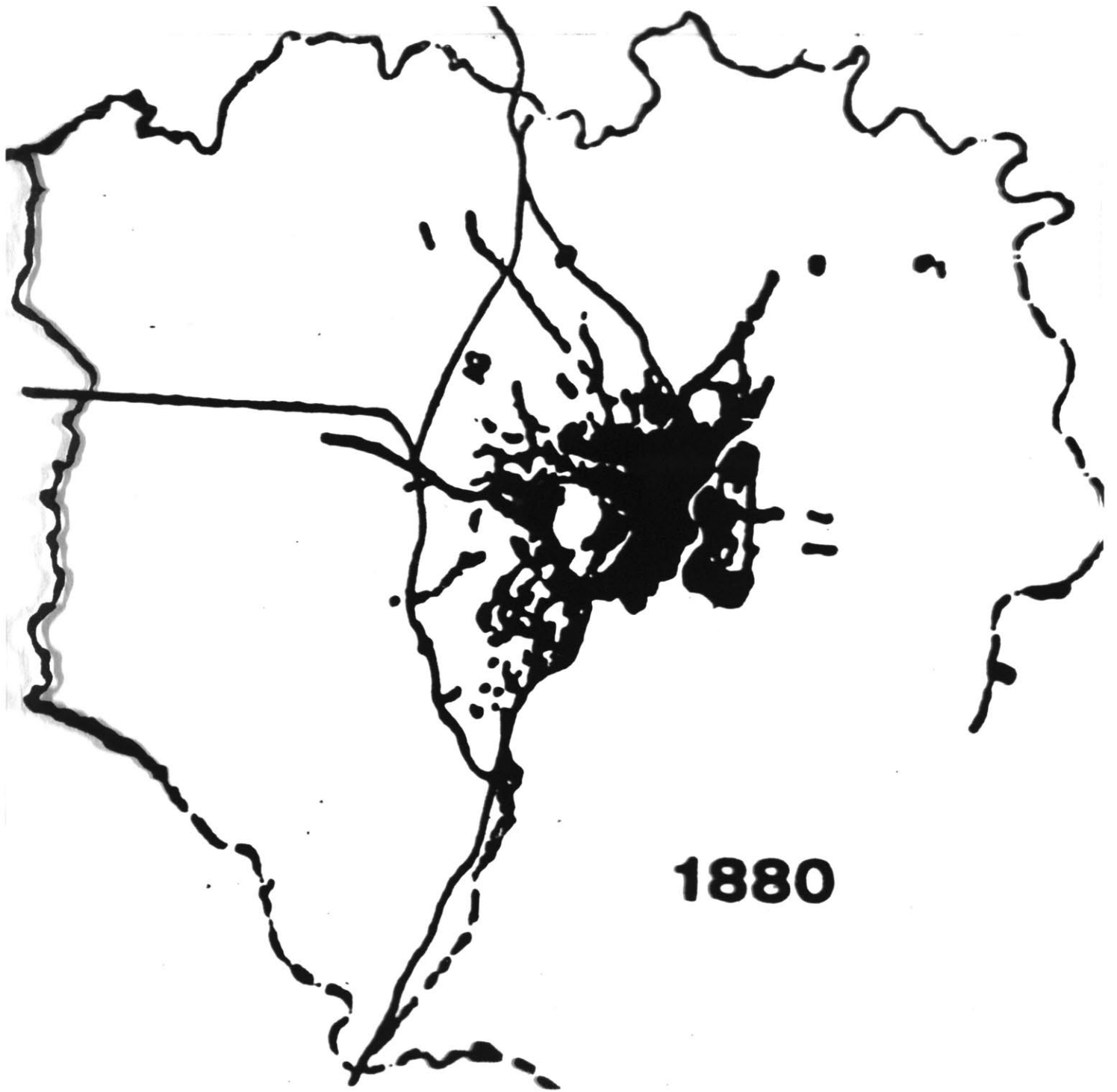
**Chapter one: The Quantitative Framework**



**1932**



1910



**1880**

THE QUANTITATIVE FRAMEWORK<sup>3</sup>

Population

Man's existence on earth has been estimated as a period between 50,000 and 200,000 years. After many millenia, or approximately 2,000 years ago, men increased in number to one-quarter of a billion people. It took another 1,600 years for the population of the world to increase by a second one-quarter billion, another 200 years to increase by an additional one-half billion; and in the past ten years mankind has added its sixth half-billion. At the present rate, it will take six or seven years to add the eighth half-billion people.<sup>4</sup> Such figures become very important in the light of the maximum estimated capacity of the world. According to Harrison Brown, the world can hold a population of 50,000,000,000<sup>5</sup> without lowering the existing standard of living. However, at the post war rate, we will double this figure by the end of the next century. There

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<sup>3</sup> Parts of this section were written in cooperation with Basil Alferief, under the guidance of Professor S. Anderson. This first chapter is not concerned with the physical aspects of this thesis, but with the context from which the assumptions and criteria have been drawn.

<sup>4</sup> \_\_\_\_\_, The Population Dilemma, The American Columbia University, Englewood Cliffs, New Jersey.

<sup>5</sup> In order to relate this figure to some existing scale, it should be noted that the world population at this moment is just over 3,000,000,000, and that it would take 45 years to count to 3,000,000,000, let alone 50 billion, according to Yona Freidman "Le Theorie des Systemes Comprehensible et son Application a L'Urbanism," Architecture d'Aujourd'hui, 34 (February 1963), 60-1.

would be one person for every square yard of land surface on the globe by the year 2700.<sup>6</sup> Thus, it is not difficult to understand the concern of some that space is the limiting factor to population increase and that available space is limited.

This calculation of population increase becomes more alarming if we consider that, presently, undeveloped areas account for two-thirds of the world population, and, by the year 2000, this same section will account for four-fifths of the world population.<sup>7</sup> Knowledge, technology, skill, and capital are concentrated in areas with the highest level of living, while the most rapid increase in population occurs in areas where such skills and capital are not relative to need. With regard to population increase, these areas do not form a unit: because of existing political barriers, population becomes a problem in specific countries before it would be a world problem, if these barriers did not exist. Taking an industrially developed society as a case in point for examining population pressures, limits the scope to a restricted area of study. Yet, if an affluent society cannot control growth's demand on its urban environment, there seems little hope for the

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<sup>6</sup> \_\_\_\_\_, The Population Dilemma, op. cit., p. 3.

<sup>7</sup> Ibid.

underdeveloped countries. Questions of policy relative to population trends are, in large part, regional and specific. An attempt to treat the United States, Africa, France, and Pakistan in the same terms is likely to promote confusion rather than enlightenment.

Less than two hundred years ago, at the time of the American Revolution, the population of the original thirteen colonies was less than three million. Today we grow by more than three million annually. Were it possible to continue accumulating as we do, like money at compound interest, America could top a three-billion total in another two-hundred year interval. Within four hundred years, unless some external restraint countered the apparent desire to procreate, this nation could anticipate a population increase of one billion every twelve months. Another five hundred years after that, or just nine centuries from now, we could delight the Internal Revenue Service by adding three trillion names annually to the tax rolls. This ought to create a good market demand for almost any useful product, and the Dow-Jones index should be all bull. What China, with its head start, would have done, meanwhile, is a calculation that should intrigue Madison Avenue.

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<sup>8</sup> Edward Higbie, The Squeeze: Cities Without Space, New York, 1960, 14-15.



At the post-war rate of 1.6 per-cent population increase in the United States per year, within one hundred years the population of the United States would be 1,000,000,000. This is equivalent to moving the total present population of Europe, Latin America, and Africa to the United States.<sup>9</sup> The large quantity of housing built in the United States before 1920, is rapidly becoming obsolete and is in need of replacement. By 1980, much of this will have become substandard. Whether this replacement can be done at a time when such vast amounts of housing are needed merely to keep abreast of population growth will depend upon the level of prosperity and the purchasing power of the population. Many economists maintain that each new unit of population brings with it added earning power (and hence, taxpaying power) to repay the community for the added facilities it must build. Others maintain that cities, increasing in size and complexity, eventually reach the point where additional units have a more than proportional cost, and the modern metropolis is reaching, or has reached, this point. In the future, population growth may impose costly financial burdens which physically-weakened municipalities will be ill-prepared to bear.<sup>10</sup>

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9 \_\_\_\_\_ . The Population Dilemma, op.

10 Barnett, op. cit.

## Energy

Power will become a primary factor in design, because nuclear fusion and second-generation power sources involving thermonuclear reaction will inevitably supplant expendable fuels.<sup>11</sup>

Energy is power, therefore the prime generator of any environment. Whether it comes in kilowats, gallons, or bushels, is of little relevance in terms of power, yet extremely important in relation to its land use. Presently, fossil fuels, such as oil, coal, and gas are the common sources of mechanical energy. Their role in influencing urban design, though, is not as great as that of the sources of human energy, as it is generally accepted that modern technology can produce energy sources far in excess of any demand. Fossil fuels, however, can disappear within the next century.<sup>12</sup> They will have to be replaced by nuclear energy; presently, less than ten per-cent of electric power is derived from nuclear fission, though it is expected that this should rise to over fifty



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<sup>11</sup> Polk, Benjamin, "The Shape of Year 2000," Saturday Review, January 23, 1965.

<sup>12</sup> Robert, Axtmann, An Appraisal of the Future of Nuclear Energy, The Hague, 1963.

percent by the year 2000.<sup>13</sup> The fission of heavy nuclei (such as the Atomic Bomb) will not be as significant a source of energy as the fusion of light nuclei (such as the Hydrogen Bomb). It is expected that as soon as the fusion of nuclear energy is harnessed, Deuterium, of which there is one-eighth of a grain in every gallon of water, can be extracted and converted into an energy equivalent to three hundred gallons of gasoline, for the price of four cents.<sup>14</sup> It is essential to concentrate upon electric power because it will increasingly become the most important energy consumption form, especially, in the post-fossil era. Certain solar energy applications, on the other hand, such as space heating or hot water heating, are much less costly than solar electric power generation and are already competitive in some regions. In all, it is safe to assume that energy sources will become less important to the urban designer and to the economist (presently, energy represents one per-cent of the gross national product).<sup>15</sup>

The problem is not mechanical energy; it is the space required to produce human energy sources. Today, each human

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<sup>13</sup> Stuart Mudd, Population Crisis and the Use of World Resources, 1964.

<sup>14</sup> A. Bishop, Project Sherwood, 1958.

<sup>15</sup> Harrison Brown, The Next Hundred Years, New York, 1957.

alive commands an area of 12.5 acres, of which almost seven are allocated to the production of food.<sup>16</sup> This ratio can be reduced by almost fifty per-cent with the use of fertilizers,<sup>17</sup> and the total agricultural acreage can support ten times the population on a vegetarian diet.<sup>18</sup> Unfortunately, only thirty-five to forty per-cent of the land in the world is available for agriculture; arid, cold, salty, mountainous, and urban landscapes compose the majority of the world's land surface. Remaining, there are 20,000,000,000 acres, one-sixth of which is cultivated crop production, one-third is meadow or pasture, and one-half is forest or woodlands.<sup>19</sup> Thus, for the time being, there is no immediate problem of space, just as there seems to be no need to worry about human storage room. Considering all the fifty states in the United States, the entire one hundred and ninety million population could be assembled in New York's Bronx and Central Parks, if we would carefully avoid standing on one another's feet. Yet, half the United States' land area would be necessary to feed these people their carnivorous diet. The Regional Planning Commission of the County of Los Angeles has prepared a graph which illustrates how human beings have spread over the farm land of that county. In 1941, the local

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16 \_\_\_\_\_ . "By 1975, What City Pattern," *Architectural Forum*, September, 1956.

17 Mudd, op. cit., p. 3.

18 Higbie, op. cit.

19 Mudd, op. cit.

population was 2,650,000, and there were 300,000 acres of agriculture soil -- a ratio of 9 to 1. By 1954, there were nearly 5,000,000 people and 225,000 acres. When the population again doubles, which is entirely possible by 1975, the farm base should be down to 75,000 acres -- a ratio of about 133 to 1.<sup>20</sup> The United States Department of Agriculture takes a dim view of Los Angeles, though it is just a pilot project in land cannibalism. Growth can no longer be solely expressed in terms of standing, eating, and sleeping room. The Department of Agriculture graphically illustrates this fact by telling us that to feed the new boarders who take a 100,000 new seats at the nation's dining table every two weeks, farmers have to plant another 241 acres of oranges, 283 acres of tomatoes, 73 acres of grapes, and 450 acres of potatoes. They also have to supply hay, grain, and pasture for 12,130 head of beef and 7,600 dairy cows. To maintain only present dietary standards, poultrymen have to provide 296,000 additional egg-laying hens, and there must be 23,000 more Thanksgiving turkeys to celebrate gastronomic bounty in traditional style.

When the limitations of space are considered, it is obvious that sometime between now and the year 2700, a Malthusian check of one sort or other will stop humanity's hectic climb toward stratospheric numbers. Of this we can be pretty certain since one square yard of

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<sup>20</sup> Higbie, op. cit.

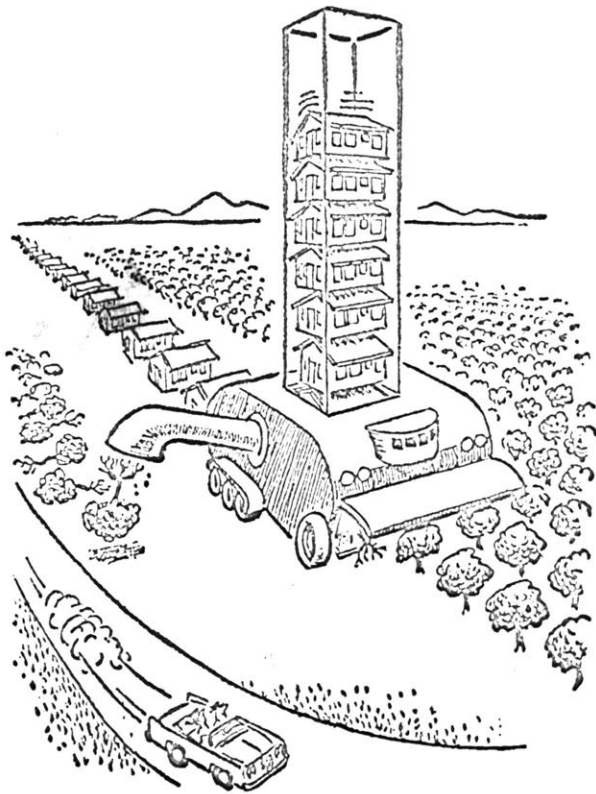
ground is considerably less than the minimum required by each member of the species, unless our descendents go in for taller multiple-story tenements and a kind of hanging-garden agriculture by which food crops would be grown like English ivy on the walls of a Baltimore apartment house.<sup>21</sup>

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<sup>21</sup> Higbie, op. cit., p. 15.

Mechanization, Transportation, and Communication

Today, we consider a machine in terms of the linear conveyor system as used by our canning and automobile industries and capable of mass producing enormous quantities of the same finished products. Yet, potentially, a machine can create dis-



tinctly different products if it is designed and programmed to do so. It is within the realm of human imagination to make such a machine. As Robert Malone has envisioned it, the machine (or factory, as it is known today) will in the future move into the home and be controlled by the user-producer.<sup>22</sup> This will be made possible by a built-in materials supply and a continuous flow system

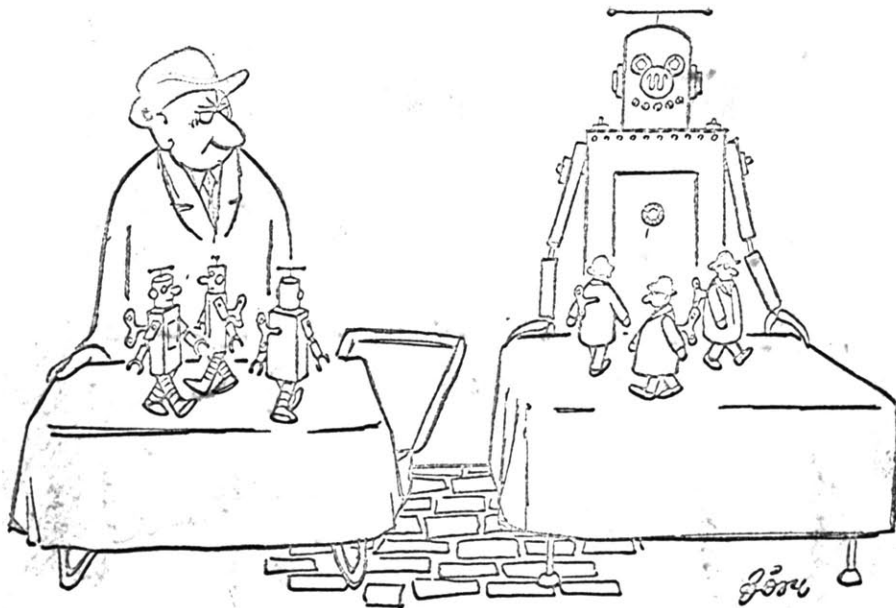
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<sup>22</sup> Lewis Mumford, *The Transformation of Man*, New York, 1956, p. 94.

with a high degree of internal integration and miniaturization, capable of self-analysis, essential modification, self-repair and maintenance, and when necessary, reproduction. Such a machine, properly programmed, would produce at a moment's notice a chair or a twenty-year old bottle of brandy, as well as food for daily meals.

Turning now to the future technological possibilities in transportation, it becomes easier to predict what the possibilities are than to place a time at which these advances will be incorporated into the culture. Thermodynamics tells us what can and cannot happen in our physical environment, but it tells us nothing about how to deal with human variables such as the adaptive capacity of man to relate to a new environment.

The notion of instantaneous transportation based on teleportation has captured man's imagination for centuries. At present, we know how to send descriptions or plans of





various sounds and images around the world at a speed which approaches the velocity of light. Using an electronic X-Ray device that could scan and faithfully record to a billionth of an inch the unique atomic structure of an individual, the device could then transmit to another system this information and have a duplicate made of this original plan. Many practical problems become evident, such as the fact that man is constantly changing biologically and that the X-Ray machine must achieve this astronomically difficult task almost instantaneously. For example, the ordinary television image has 250,000 picture elements and the body has  $5 \times 10^{23}$  atoms. At our present level of electronic sophistication, it would take  $2 \times 10^{13}$  years to transmit a matter image of just one individual.<sup>24</sup> Because the idea of teleportation has a "science fiction" quality, we cannot assume, for the purposes of this paper, that this type of instantaneous travel is feasible in the future; we must step back to the mundane notion of the highway, railroad, and airplane.

By acquiescing to one traffic emergency after another, as though only a little face-lifting were necessary, metropolitan areas have allowed themselves to be overpassed, widened, straightened, and segmented by "gasoline gullies" and "Chinese walls" ad infinitum; yet, the headaches of congestion grow faster than the fresh supply of asphalt aspirin.<sup>25</sup>

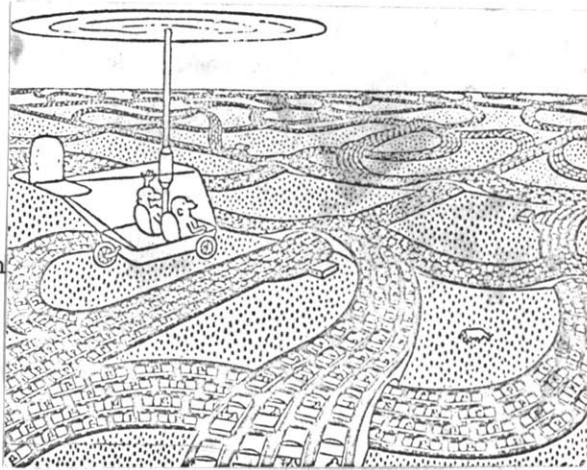
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<sup>23</sup> Arthur C. Clarke, *Profiles of the Future*, New York, 1958, p. 61.

<sup>24</sup> Clarke, op. cit., p. 61.

<sup>25</sup> Higbie, op. cit., p. 192.

The automobile has assumed such a role in society that it has not only changed our environment radically, but it has assumed an anthropomorphic role for demographers. The car population increase has constantly exceeded, since 1946, the net human population increase: an increase of 26,000,000 from 1945 - 1956 and an increase of 50,000,000 from 1956 - 1966. The majority of these cars live in the city, and must be accommodated with sufficient surface on which to flow. The extent of these surfaces become powerful political and urban form-givers. New York's construction coordinator, Robert Moses, recently recommended to the Board of Estimate that eighty-three million dollars be spent to build two and one-half miles of elevated highway in lower Manhattan so that traffic might flow from the Holland Tunnel and the West Side Highway to the Manhattan and Williamsburg Bridges across the East River. This, in the words of Mr. Moses, would be "a key to the resurgence of the entire downtown area."<sup>26</sup> This poignantly



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<sup>26</sup> New York Times, November 13, 1959.

illustrates that we have well passed the point of diminishing returns with the automobile in the center city. It has been estimated that if an additional 75,000 daily commuters were to try to get from New Jersey into New York City by automobile, it would require ten more vehicular tunnels under the Hudson River and twenty more lanes of expressway into the city. The same load can be supported on one double-tracked railroad entering the city either above or below ground.<sup>27</sup>

The automobile has exploded the metropolis open, and no amount of public transit will jam it back together again. The automobile looks like an unbeatable invention for circulating people from low density communities to low density activities of all kinds. However, there seems to be no rational place for it in our urban Humpty Dumpty.

Instantaneous communication is a force that has made faster in-roads into our society than any of the other forces, real or imagined, discussed thus far. Today, with the advent of Telstar, all continents are tied visually together in time. Arthur Clarke predicts the time when all men (given, of course, a telephone number at birth) will be able to reach each other any place on earth simple by dialing a miniaturized transistor telephone.<sup>28</sup> The invention of the telephone in our era has shown

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<sup>27</sup> Editors of Fortune, The Exploding Metropolis, Garden City, New York, 1958.

<sup>28</sup> Clarke, op. cit., p. 61.

how a new communication system can transform social and business organizations. However, with instantaneous communication, one runs into further danger of alienating direct human experience. Implicit in technological revolutions, is the necessity of a social revolution, the creation of a society which can assimilate a world controlled by remarkably advanced inventions. Can man, in fact, adapt physically and emotionally to the future world? One thing does seem obvious: even though we can imagine startling technological advances, some even in the immediate future, it will take much longer for men to assimilate these advances into his culture and his past way of life.

Inevitably, the time will come when cultural and social patterns, due to the spiraling progression of future prediction, will need to undergo an almost sudden adaptiveness. This is had to envision, since, in general, major cultural changes have taken place in society on a time scale measured from one generation to another. This unit of measure, based on our patterns of culture, will not be sufficient in the future. Brothers and sisters will be born into different eras.



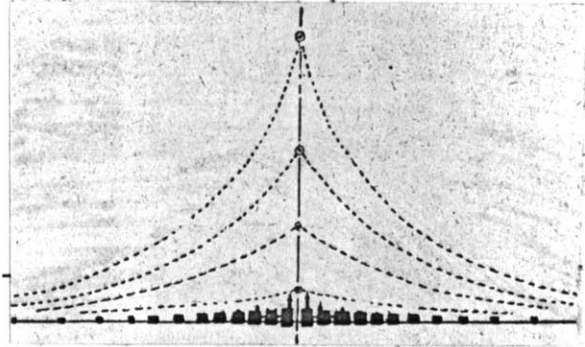
## Chapter two: The Physical Response



## THE PHYSICAL RESPONSE

### Growth

A physical system starts smaller than its optimum size. Its internal functions provide the impetus for growth, though after a certain size the original functions change. At the Optimum scale, a decline in efficiency sets in, and new functions are found to accommodate an even greater size. (Less flexible species in history often perish from gigantism when the generated demands cannot be met by the environment.) The morphogenesis of an organism entails a biological development characterized by the enlargement of its cells. This enlargement is accomplished largely by the absorption of new materials into the interior of the cell.<sup>29</sup> It is obvious that all growth in a cell wall must proceed in the conventional built-up fashion which process requires the skillful intercalation of reinforcing elements lest they become merely attached to the surface. It is likely that the wall during periods of expansion, caused by internal pressure, absorbs new materials, which become precipitated in the available interspaces.<sup>30</sup>

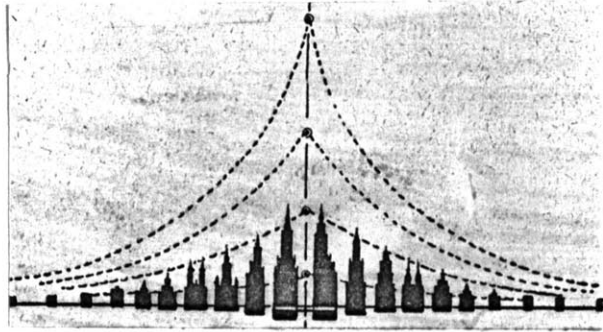


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<sup>29</sup> Wilhelm Block, Systematics of Dichotomy and Evolution. Pennsylvania, 1962.

<sup>30</sup> John T. Banner, Morphogenesis, Princeton, 1952.

Gravitation and heat, are the prominent forces in biological development.<sup>31</sup> Biological development is a good reference for the study of urban growth. Though not affected greatly by heat and gravitation, a city grows only due to a set of economic, social, and environmental forces, in relation to time. It is this transient frame of reference, the relation of old to new, that permits us to pick and choose from the laws of natural growth.



In the great majority of cases, when we consider an organism in part or whole, when we look (for instance) at our own hand or foot, or contemplate an insect or a worm, we have no reason (or very little) to consider one part of the existing structure as older than another; through and through, the newer particles have been merged and comingled among the old; the outline, such as it is, is due to forces which for the most part are still at work to shape it and which in shaping it have shaped it as a whole. But the horn, or the snail-shell is curiously different; for in these the presently existing structure is, so to speak, partly old and partly new. It has been conformed by successive and continuous increments and each successive stage of growth, starting from the origin, remains as an integral and unchanging portion of the growth structure.<sup>32</sup>

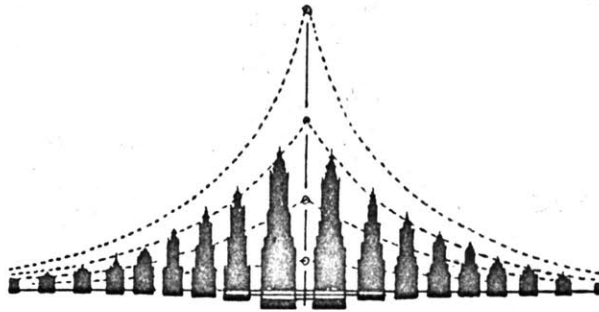
When one sees in a shell a close approximation to a sphere or a spiral, one is prone, by habit, to believe that after all it is

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<sup>31</sup> D'Arcy Thompson, On Growth and Form, Cambridge, 1952.

<sup>32</sup> Ibid.

something more than a sphere or spiral, and that in this something more, there lies what invalidating, in this case, the application of Nature's laws to urban growth. According to Janet, though, the urban designer is exactly like nature, searching for the simplest means to accommodate a specified environment:



La Nature agit toujours par les moyens les plus simples et chaque chose finit toujours par s'accommoder a son milieu.<sup>33</sup>

A specific environment controls the rate of growth and not the process. Site conditions determine land-uses, industrial distribution and lines of communication, but do not effect unit sizes, generated by man's needs.

The form of an organism is determined by its rate of growth;<sup>34</sup> The rate of growth is in turn a function of the environment. Thus, we should not concern ourselves with form, in the study of urban growth, but rather with order. An entirely new way of looking at the city is necessary. It is not the "Image of the City" but the system of the city that must be subjected to an order of growth. Form to Aristotle was metaphysical concept: to us it is a mechanical effect of forces on a system. In cities, the change in form

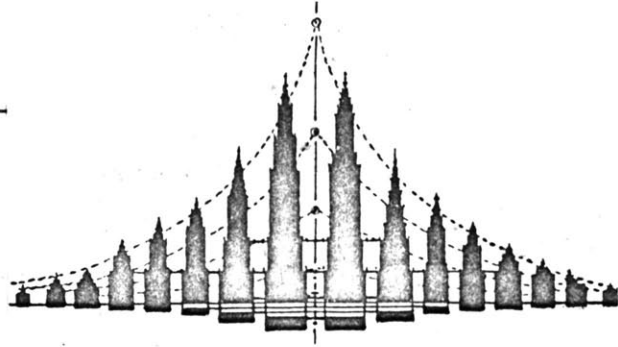
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<sup>33</sup> Janet, Les Causes Finales, 1876, Page 350.

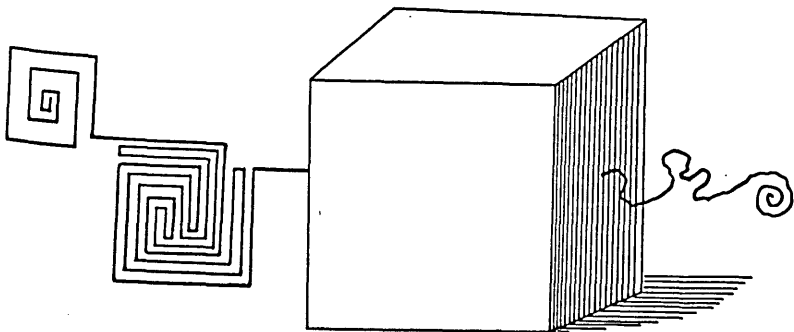
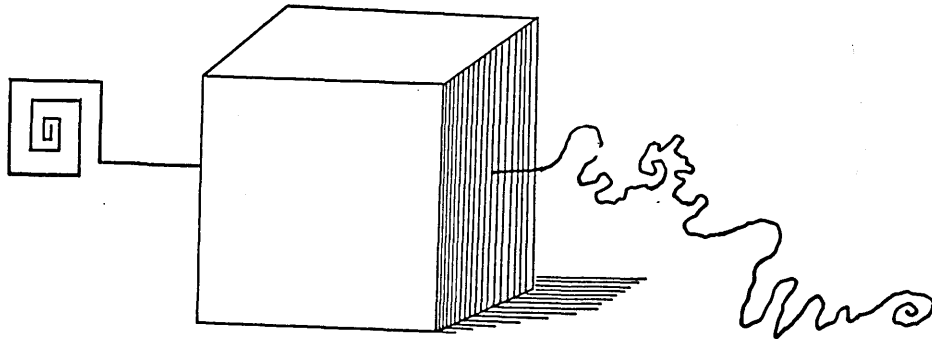
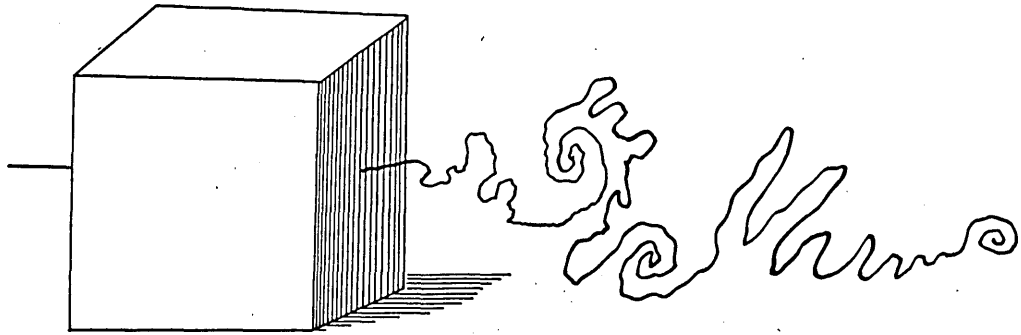
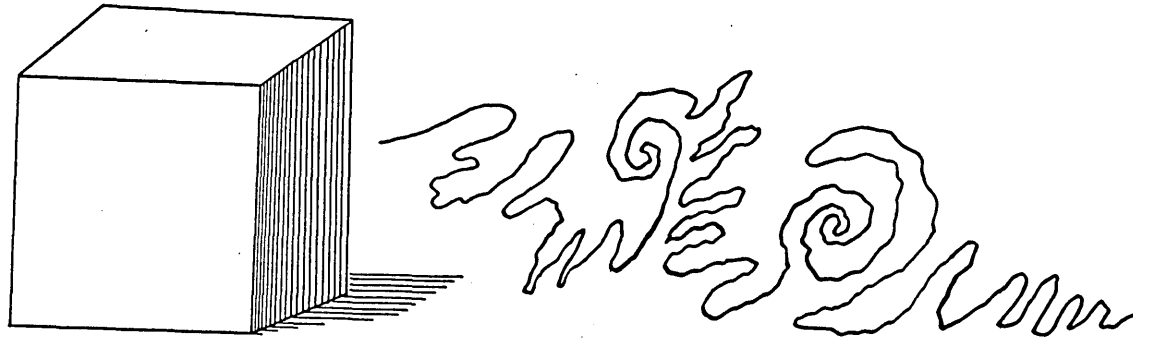
<sup>34</sup> Thompson, op. cit.



should be generated by varying the forces and keeping the system constant; thereby generating an infinite number of forms with a single given order. Form should not be static; but, a phenomena of morphological development.



It is the above concept that has been the most difficult with which to deal. The study of sizes, of the parts, and of geometrics has been the only way to study growth as a system. It has been necessary to find a set of building blocks which are part of an order of growth, that under given forces will produce form.



## Size

Athens, in the fifth and fourth centuries, had a citizen population of 40,000.<sup>35</sup> But few other Greek cities exceeded 10,000 in population. Hippodamus maintained that 10,000 was an optimum size; Plato, that 5,000 to 10,000 was optimum.<sup>36</sup> These population figures were based on a certain well defined set of technological conditions. Without change in these technological conditions, urban growth could not have been an issue in urban theory. Urban decay, suburban sprawl, rising taxes, clogged highways, distressed railroads, and disappearing recreational space are symptomatic of the environmental illness which saps urban vitality.

Designing an urban system cannot involve a high degree of adaptation nor the concept of an optimum size, as its efficiency should change in accordance with its growth; the demands must increase with the urban core.

Hume, in his essay, "On the Populousness of Ancient Nations," set the maximum population of Carthage, Peking, Constantinople, London, and Paris at about 700,000 each and he conjectured:

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<sup>35</sup> A total population of between 100,000 and 150,000 including slaves and foreigners.

<sup>36</sup> Arthur B. Gallion, The Urban Pattern, Van Nostrand Company, 1950.

... from the experience of past and present ages there is a kind of impossibility that any city can ever rise much beyond this proportion.<sup>37</sup>

Sir William Petty, writing a hundred years earlier, figured as the upper limit of London's population, 5,000,000. According to his reasoning, if the population of London continued to double every forty years as it was then doing in 1686, by 1842, it would have a population of 10,718,889; but, also in 1842, England, whose population would double only once in 360 years, would have only 10,917,389 persons. It was obvious that the 200,000 people in England outside of London could not supply the city with provisions. For each man in the city, there would have to be another who was an agriculturalist. Thus, he concluded, London would stop growing the next preceding period (in 1800), when it would have a population of about 5,000,000, leaving almost 5,000,000 "to perform the tillage, pasturage, and other rural work necessary to be done without the said city."<sup>38</sup> He was unable to foresee that even one hundred and fifty years later London would be able to draw its wheat from Dakota, Manitoba, Argentina, and India. In fact, he demonstrated that a city's food supply could not be brought from a greater distance than thirty-five miles. Cattle, he stated, can bring themselves from a dis-

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<sup>37</sup> Hume, Essays, Edinburgh, 1817.

<sup>38</sup> Sir William Petty, "Essay on the Growth of the City of London," Essays on Political Arithmetic, 1755, p. 16.

tance of about thirty-five miles; the ground enclosed in a circle whose radius is thirty-five miles will provide bread and drink, corn, hay, fodder, and timber for 600,000 houses,<sup>39</sup> -- equal to a population of about 5,000,000.

Even today, City Planning Theorics are restricted by demographic limits:

Some simple rules of thumb taken from demography suggest that toward the middle of the next fifty-year period a city of twenty-five million can exist. Such a concentration would be unworkable if either external supply or internal distribution should prove too expensive. There is almost no possibility of an absolute failure. I assume that the entire population of the country will always be adequately supported. If there are no national shortages, then the external supply is a problem of import, and therefore of total channel capacities: port, rail, truck, and air. About five times New York's capacity is a reasonable estimate, and this looks easily attainable from the present capabilities of the large seaport cities, without any substantial increase in the unit cost. However, supply will not have to depend on present means. Capacity will increase as pipelines and airlines move more deeply into the freight business, and channels will be used more intensively as cargo juggling becomes easier.<sup>40</sup>

Some demographers, meanwhile, recommend restrictions size to maintain efficiency. Gertler maintains that between 250,000 and 500,000 lies the point of maximum efficiency. He further suggests that if we are to carry out a particular strategy

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<sup>39</sup> Ibid., p. 23.

<sup>40</sup> Aaron Fleisher, "The Influence of Technology on Urban Forms," The Future Metropolis, Daedalus, Winter, 1961.

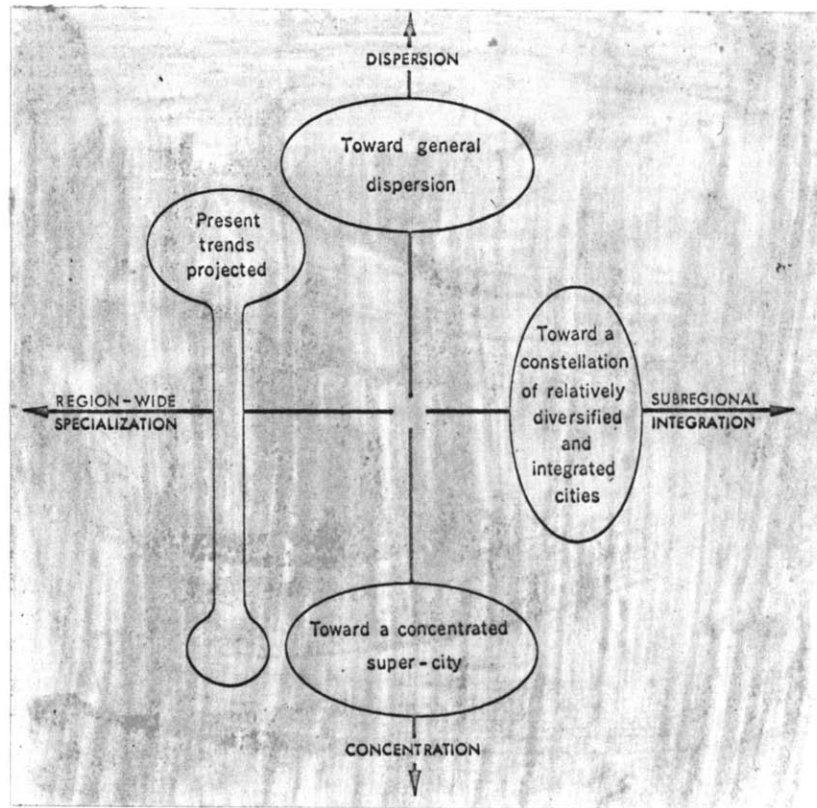
of growth and maintain an optimum size, we will be establishing the conditions, not only for preserving whatever good qualities of the city already exist, but for adding to them. For, as the optimum size of the center is approached, the new demands for roads, sewers, and water lines will decline; and the city will consequently be able to accumulate capital or borrowing power for the improvement of conditions in older areas.<sup>41</sup> Such restrictions in size seem to indicate that diversity will turn into uniformity after a point of inflection is reached and that the urban problem will not be any longer dimensional, but psychological.

The advantages and disadvantages of concentration, dispersion, and general size seem to be more important than man's desire to wrap himself in a small package whose size is controlled by environmental restriction. Limiting city growth is an activity of the past, dating as far back as Cicero's attempts to stop the emigration from the country into Rome. Justinian tried to stem the tide through legislation. Medieval rulers followed a similar course. The expansion of both Paris and London has frequently, but unsuccessfully been prohibited by law.<sup>42</sup> Extension, quantitatively, is a natural phenomenon and should seriously be considered qualitatively.

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<sup>41</sup> Mudd, op. cit.

<sup>42</sup> Anna Ferrin Weber, Ph.D. The Growth of Cities in the Nineteenth Century: A Study in Statistics, New York, 1899, p. 454.



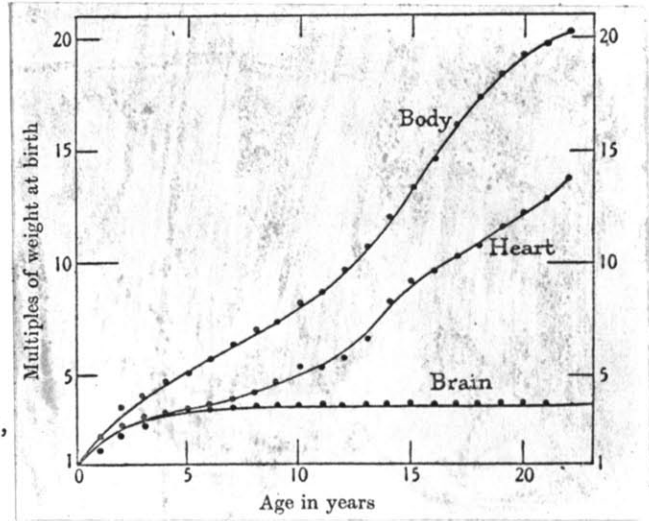
The above diagram shows Catherine Bauer Wurster's summation of man's propensity to seek diverse directions.<sup>43</sup> This leads to a multiplicity of structures because each direction has an integral matrix, provoked as a reaction towards existing conditions. All of the above conditions can happen at their proper scales: a problem of form. It is the parts that are constant and must follow an order of growth.

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<sup>43</sup> Catherine Bauer Wurster, "Form and Structure of Future Urban Space," Cities and Space, Washington, D. C., 1963.

### The Parts

The many components of a varying organism, have rates of growth. The accompanying graph, indicates the "relative growth in weight of brain, heart, and body of a man. In nature,



this unequal growth is reversable for when an organism starves, the growth curves are retraced. Chossot found, for example, that a pigeon starved to death had lost 93% of its fat, about 70% of its liver, and 40% of muscles, and about 2% of its brain and nervous tissues.<sup>44</sup>

Due to built-in efficiencies and functions, the components of an urban body also grow unequally; growth in housing is the most rapid, and the most extensive. On a square foot per capita basis, housing "cells" at the mature stage in growth, represent 80%<sup>45</sup> of the urban fabric.

As an indication of the relative growth of various urban functions, the following table has been arranged. It will be referred to in later sections.<sup>46</sup>

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<sup>44</sup> Thompson, Op. Cit.

<sup>45</sup> This figure has been calculated by the author, using both the figures of Gallion and Doxiades.



THE EFFECT OF POPULATION GROWTH UPON THE EXPANSION  
OF URBAN FACILITIES

<u>Population</u>	<u>Facilities Added</u>
150	One general store
250	Market, drugs, bar and grill
1500	Stationery, laundry cleaner
3000	Specialty shops, delicatessen, beauty shop, bakery
7500	Market, drugs, stationery, laundry, restaurant, barber, florist
115,000	Market, drug store, theater (1200 seats) variety shops, post office, professional offices, gas station, youth center, public car parking
30,000	Library, 3 theaters, police station, churches, fire and ambulance service, clinic, public hall, secondary school, minor athletic facilities, service industry
60,000	Complete retail and professional center, town hall, art gallery, hotels, ware-housing, stadium

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<sup>46</sup> This Table was compiled from four sources:

The Planning of a New Town, London County Council, 1961  
Architectural Forum, Article by R. Dowling, October 1943  
Gallion, op. cit.  
Doxiades, op. cit.

The above table, can be extended until the familiar landmarks of a mature city are included: universities, airports, opera houses, etc. However, the older the species, the more the physical changes rely on environmental conditions rather than size. After a certain size, each variety of function will be urgently and absolutely called upon to produce its title of existence as an active agent or as a survivor. The evolution of the parts has its physical analogue in universal law -- the principle of entropy -- that the world tends in all its parts and particles, to pass from certain less probable to certain more probable configurations or states.

## Dimensions

In Lilliput, "His Majesty's Ministers," finding that Gulliver's stature exceeded theirs in the proportion of twelve to one, concluded from the similarities between their bodies that his must contain 1728 ( $12^3$ ) of theirs, and must be fed accordingly. Swift paid close attention to the arithmetic magnitude, but none to the physical aspect.

A fish can grow in length from 4 inches to 5 inches and double its weight.<sup>47</sup> Accordingly, dimensions within, for example, can double and support eightfold increase of population. Yet, within a system, the parts have their appropriate dimensions and their more or less narrow range of absolute magnitude. Galileo pointed out, that if we tried building ships, palaces, or temples of enormous size, beams and bolts would cease to hold together; nor can nature grow trees nor construct an animal beyond a certain size, while retaining the proportions and employing the materials which suffice in the case of a smaller structure. The thing will fall to pieces of its own weight unless we change the relative proportions, which will at length cause it to become clumsy, and inefficient, or else we must find new materials, harder and stronger than the ones used before and add them appropriately.

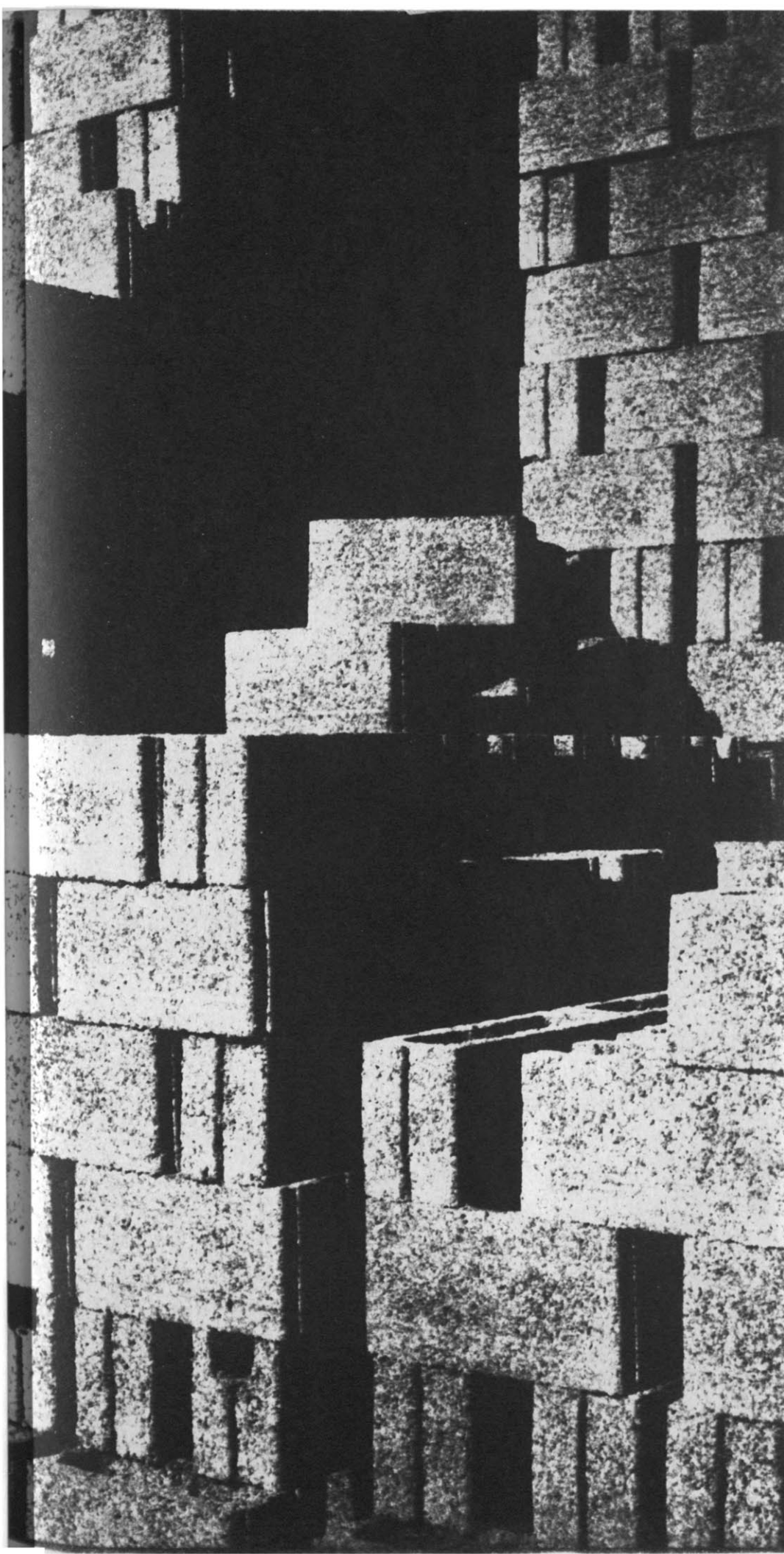
Nature uses materials of predeterminate dimensions. She uses the same size "bricks", whether she builds a great or a small

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<sup>47</sup> Thompson, op. cit.

"house," only the strength of the "brick" is varied. The size of cells are determined by function. "The individual cells of skin, gut, liver, muscles, and other tissues, are just the same size in one as in the other, in dwarf as in giant."<sup>48</sup>

Urban cells are the same. A residential unit in a small town has the same dimensional relationship as one in a large city, as both are governed by the dimension of man and his needs. The direct relationship of cell size to cell use in nature, has suggested the course of study of urban form and growth. It is the life, birth, and death, process of the cells, in microcosm, that determines the macrocosmic growth of the city. The relationship of the various urban dimensions provides the basis for a system of urban growth.



## Geometrics

Patterns of urban form is a dangerous subject. Serious city planners and architects are sure that it is the forces of economics and transportation, government and land tenure which shape the city and that pattern mongers are pipe dreamers. And yet, when it actually comes down to brass tacks, when cities, extensions of cities or new housing areas have to be built, we all turn to a set of models - or patterns - and, consciously or unconsciously, form our projects accordingly.<sup>49</sup>

All patterns or models, though, are merely an articulation of a pattern of life: concentration, meaning: exchange, competition, convenience, multiplicity of choice, swift cross-fertilization of ideas, and variety of demand; scatteration: meaning privacy and contact with the earth.

According to Frank Lloyd Wright, we had prohibition because a few fools could not carry their liquor; Russia has Communism because a few fools could not carry their power; and we have overly concentrated cities because a few fools cannot carry out their designs. For Broadacre City, he makes three assumptions:<sup>50</sup>

1. Given electrification, distances are all but annihilated so far as communication goes.

2. Given the automations of machinery, a human labor relatively disappears.

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<sup>49</sup> Jacqueline Tyrwhitt, "Shapes of Cities that Can Grow," Architectural Association Journal, 79:876 (November, 1963).

<sup>50</sup> Frank Lloyd Wright, The Disappearing City, New York, 1932.

3. Given mechanical mobilization, the steamship, airship, automobile, the mechanical human sphere of movement immeasurably widens by way of comparative flight.

There are the criteria for Broadacre City. Such form assumptions, rendered with formal geometries, are derived from basic personal values on the part of the planner. Frank Lloyd Wright felt that it is necessary for man to retain his biological bond to the earth.

At the same time, Le Corbusier, was working at the other extreme in both his New York plan and Ville Contemporaine, with densities ranging from 400 to 1200 persons per acre. Such schemes are much more relevant to problems of growth since the need for an urban form that can absorb considerable growth and change without destroying itself must have a basic physical totality.

Death can continue to dwell in the same sepulchre,  
but life must increasingly outgrow its dwelling  
place; otherwise the form gets the upper hand and  
becomes a prison . . .  
Life is a creative idea, it can only find itself in chang-  
ing form.

Rabindranath<sup>51</sup>

The whole problem becomes no longer a static one, but rather, the understanding of a dynamic system that can grow and change -- an organism.

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<sup>51</sup> David Crane, "Dynamic City - Chandigarh," American Institute of Architects Journal, May, 1960.

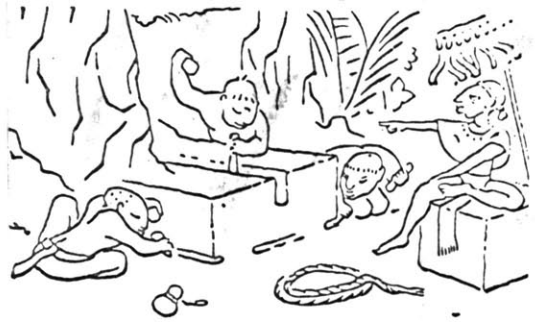
An organic system of growth, meanwhile, can be planned to adapt and change, rather than be flexible enough to accommodate. It would also imply that any growth is reflected throughout the system. This can easily get out of hand, using urban design as the analogue, since the expansion of the city would mean the expansion of the city hall, which would mean a larger assembly room, with larger doors, and larger door knobs. What is merely meant is that with every quantitative change, there is a qualitative change. In Nature this is expressed by dichotomization, whereupon an organism grows quantitatively to a certain size at which point there is a dichotomy, the qualitative change that takes place in order to generate new growth.

In a city, this quantitative-qualitative relationship must exist within a geometry, one that allows as many degrees of freedom as possible within an order. Ideally, this would be an infinite number of autonomous points in space, into which or onto which urban cells can be attached. Since, such a system entails maximum redundancy, an order should be found that gives freedom, but under a certain restrictive geometry. The danger here, is understanding the word "geometry" as described in a high school math course, and producing an urban straight-jacket. After all, this geometry must bind together man, not merely lines and circles, on the assumption that the city will not become obsolete.



### Sociological Forces

Man is basically a social animal; this aspect of human nature has not changed since Paleolithic times and will not change in the future.



Men choose to live

together. They crave

a sense of belonging and a sense of identity, intensified by a recognizable sense of place. When given the whole world as his potential environment, man will find it impossible to assimilate and identify with the entire scale of world culture; rather, he will seek refuge in a small tangible, spacial unit with friends and community on a more intimate scale.

The need for taking part in communal celebrations not in vast anonymous masses, but in a circle of identifiable faces and persons, survivals of aboriginal village life, are still necessary. They keep intact the close chain of sympathetic response in which man first securely established himself as irrevocably human: these friendly eyes are the indispensable mirror in which the self beholds its own image.<sup>52</sup>

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<sup>52</sup> Lewis Mumford, The Transformation of Man, New York, 1956, P. 94.

Without intimate relationships, men become things. So, even though man will have in his power the choice of many places in which to establish friendships, to work, and to travel, he will still need a home base where close, day-to-day human contact will give him emotional stability, and, indeed, personality and "humanness, "

Most certainly, continued progress in travel and communication will add new choice and excitement in life. Yet, man will continue to find the drama of existence in his struggle to relate to his society as well as to his environment. Hopefully, man will circumvent the prophecies of many leading minds of the future development of an automaton existence, devoid of the creative imagination which gives the ideas and impetus to the realization of such a world. The ultimate development of the automaton will certainly be realized if man does not give fundamental re-evaluation to the basic role of technology in our society.

Technology must be made to serve the needs of man and not become technology for technology's sake. In other words, we must decide on goals for technology and then integrate these goals into the social framework.. There always exists the great problem of keeping technology humane and attuned to the fundamental character and needs of man. This problem is becoming increasingly more difficult as scientific knowledge probes deeper

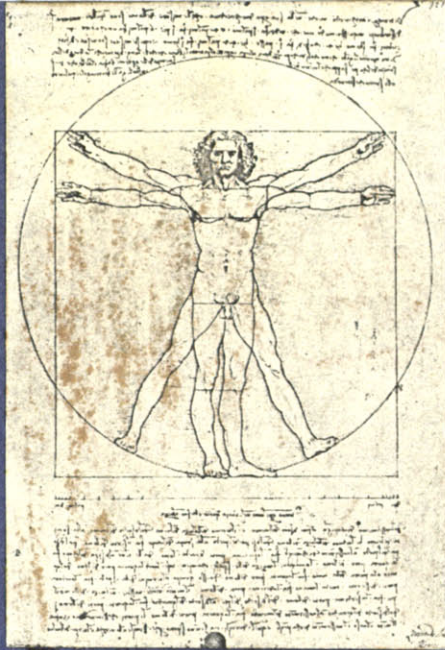
into phenomena not related to direct human experience. Science continues to move further and further from common experience, and thus, the breach between the world of science and the world of "man" grows wider and wider.

Science and technology, in addition to demanding enormous adaptive changes from social man, also unwittingly shapes culture. For example, Darwinism, a scientific principle, in the late nineteenth century, was applied to society and social changes. It undermined the basis for religion; it became a social justification for the "survival of the fittest" in the cultural realm. Men rationalized their ruthlessness in the free enterprise system in terms of social Darwinism. History shows us the disruptive effect of science on culture. So, our continuing problem in the future will be the assimilation of science and our wrestling with its disruptive influences.

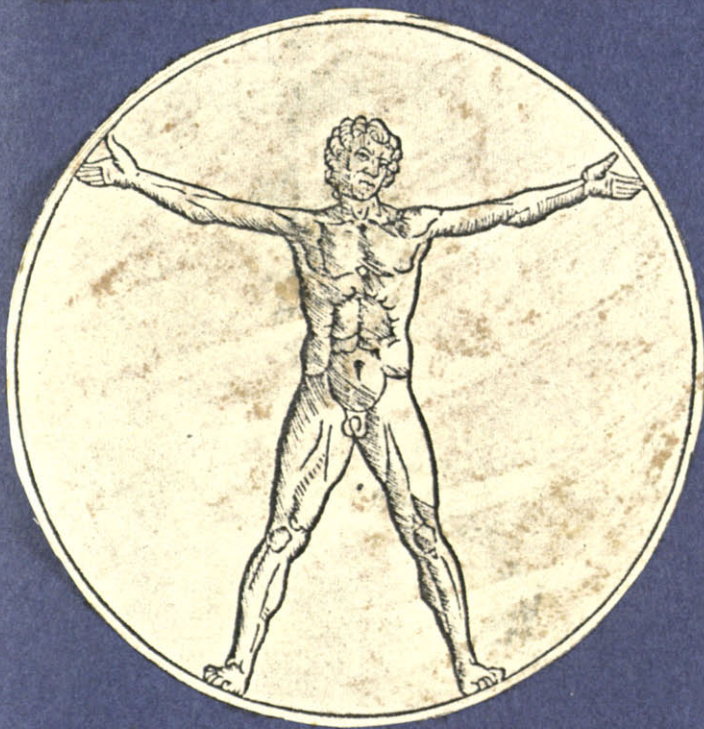
Even with new forces of the order and magnitude discussed, we find that man still has the ability to assimilate into his culture only those things which he chooses. By so doing, he does not become a new animal, but he continues the slow evolutionary cycle of human development.

Man will in the future world still find a basic human need for close spatial companionship, even though in time, he might be offered the same relationship over a larger spatial area due to new systems of travel. Man will bind with other men because of his in-

nate desire for social and psychological identity and social contact. He will not choose to live in spatial isolation nor will he abandon cities, or the idea of concentration centers, as places for worship, for cultural pursuits, for intellectual stimulation, and for social communion. The new city will unquestionably have a new form, but the city will not become obsolete.



### Chapter three: Systems



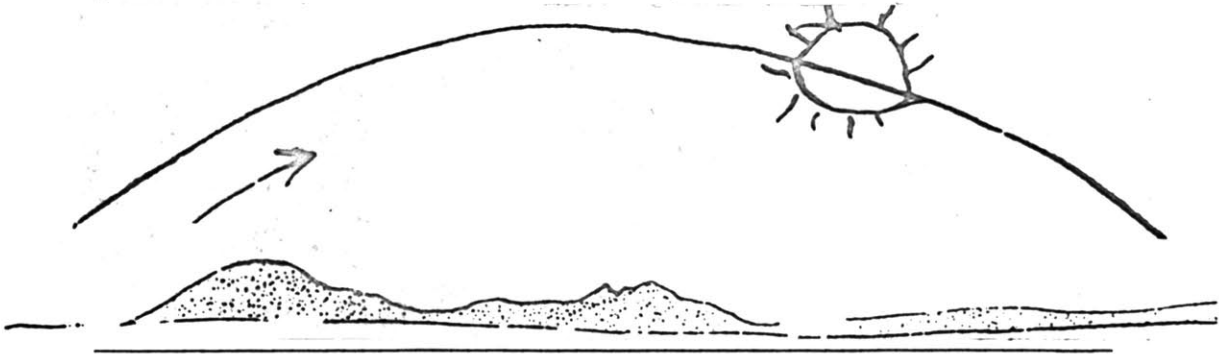
## SYSTEMS

### Symmetrical Systems

"An organism is so complex a thing, and growth so complex a phenomena, that for growth to be so uniform and constant in all parts as to keep the shape symmetrical and unchanged would indeed be an unlikely and unusual circumstance."<sup>53</sup>

Among animals, symmetry is confined to very small creatures where the governing force is internal and symmetrical, such as surface tension. In the small world of the protozoa, some degree of spherical symmetry becomes a rule, until gravity can resume its sway. At this point, all manners of structural differences come into play within the growing system, and set up unequal resistances to growth in one direction or another.<sup>54</sup>

In short, the form of an object is a diagram of forces, a symmetrical form assumes symmetrical forces. This is obviously impossible to find in an environment, for, if nothing else, the path of the sun dictates directionality.

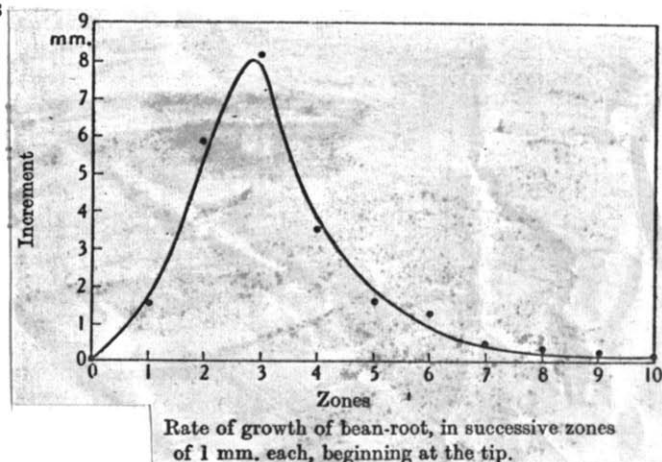


<sup>53</sup> op. cit. Thompson

<sup>54</sup> Ibid.

Although the axiom is clearly perceptible, it took several months of working on a totally symmetrical system, to realize its inherent flaws.

Force demands a rate and it is this rate that will govern form. A symmetrical form would require constant rates of growth for the parts. In other words, graphically, the curve of growth,<sup>55</sup> for each part, would have to be a straight line. This is impossible, as even the increment of parts within a body is unequal when taken between two discrete points in time.



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55 A curve of growth is a graph of increment over a period of time and, by implication, is a "time-energy" diagram. As D'Arcy Thompson points out, a man grows and absorbs energy beyond his daily needs, till the time comes when he accumulates no longer, and is constrained to draw upon his dwindling store.

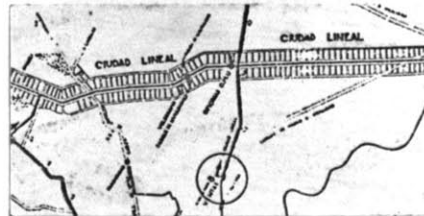
## Linear Systems

'A single street of 500 metres' width and of the length that may be necessary -- such will be the city of the future, whose extremities could be Cadix and St. Petersburg, or Peking and Brussels.

'Put in the centre of this immense belt trains and trams, conduits for water, gas and electricity, reservoirs, gardens and, at intervals, buildings for different municipal services -- fire, sanitation, health, police, etc. -- and there would be resolved at once almost all the complex problems that are produced by the massive populations of our urban life.

'Our projected city unites the hygienic conditions of country life to the great capital cities and, moreover, assumes that the railways, like today's streets and pavements, will carry free or for little all citizens.'<sup>56</sup>

Many villages in the past developed along major country roads. However, it was only at the end of the Nineteenth Century that city planning acknowledge transportation as an urban generator. Arturo Soria y Mata (1844-1920) was the first to draw attention to linear planning and devised his Ciudad Lineal, in the course of writing an article about municipal reform.



Soria's planning ideas are illustrated in the above quote and adjacent illustration. Much refinement and experimentation has been done with Soria y Mata's

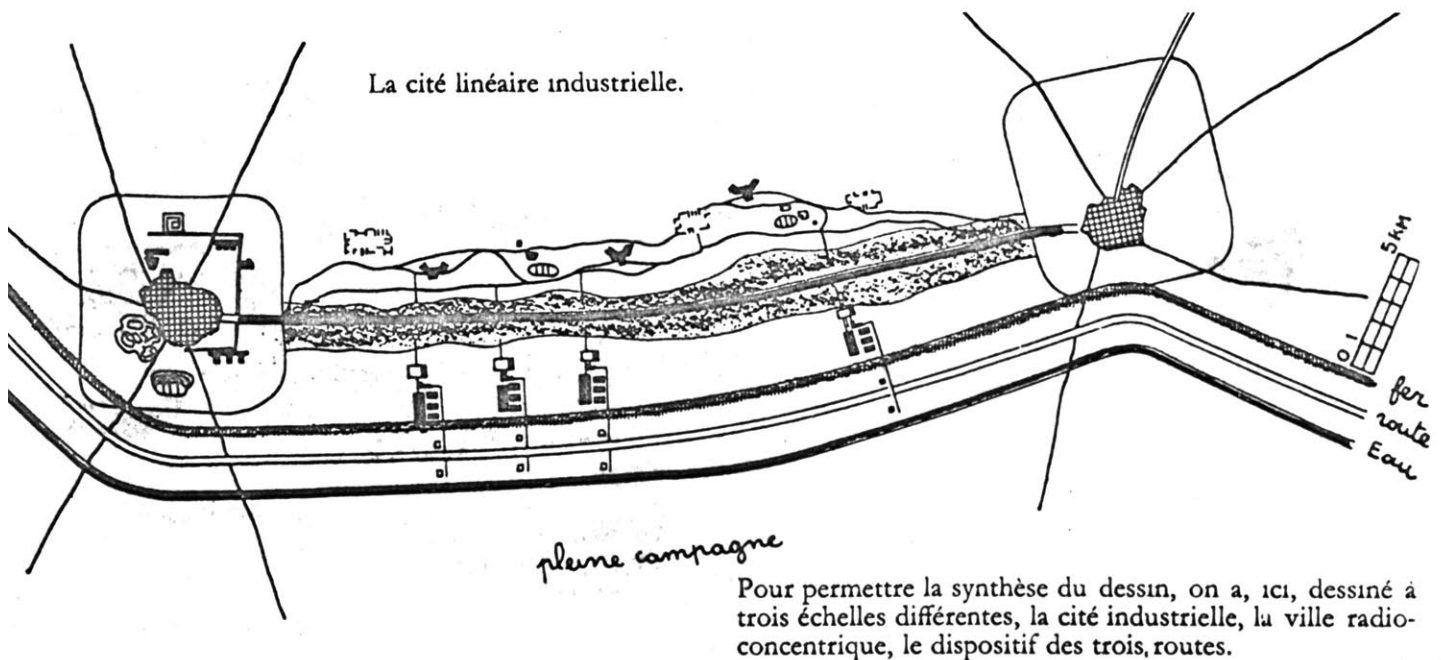
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<sup>56</sup> Part of Arturo Soria y Mata's article in *El Progreso*, (March 6, 1882), a radical and short lived Madrid newspaper, quote by George Collins.



original ideas. In 1910, Edgar Chambless proposed in his "Roadtown" project, a continuous concrete house, indefinitely long, snaking across the countryside with its own rapid transit system in the basement.<sup>57</sup>

Le Corbusier's linear industrial city was developed during the war years. Set in the middle of agricultural lands, his linear city performed one major function: uniting "les Cities Radioconcentriques des Echanges." Attached to the linear city, like dry cells, are the industrial units that make up Corbusier's



Usines Vertes. The above diagram, taken from L'Urbanisme des Trois Etablissements Humains,<sup>58</sup> shows this concept diagrammatically.

<sup>57</sup> George R. Collins, Architectural Review, "Cities on the Line," November 1960.

<sup>58</sup> Le Corbusier, L'Urbanisme des Trois Etablissements Humains

Translating the principles of linear planning, into growth systems, is usually when the linear plan falls apart. At the birth of a linear plan, very strong lines of force are set up. So strongly, that most planners let the linearity assume a supernatural predominance in organizing the urban topography. However, a more natural course would be to let the linear system acquire a more "stable" form during its growth process.

In other words, for experimental demonstration, the case of cylinder is the simplest, as it is a pure linear system. If the cylinder is constructed by either drawing out a bubble or by supporting a globule of oil between two rings, the experiment proceeds easily until the length of the cylinder becomes just about three times its diameter. Afterwards, instability begins and the cylinder alters its form:

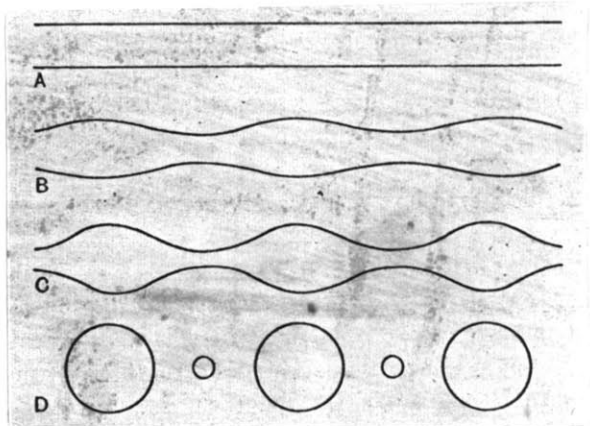
It narrows at the waist, so passing into an unduloid, and the deformation progresses quickly until our cylinder breaks in two, and its two halves become portions of a sphere.<sup>59</sup>

This physical change from one surface to another corresponds to what the mathematicians call a "discontinuous solution" of a problem of minima.<sup>60</sup>

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59 Thompson, Op. Cit.

60 The theoretical limit of stability, according to plateau, is when the length of the cylinder is equal to its circumference, that is to say, when  $L = 2\pi r$ , or when the ratio of length to diameter is represented by .



In urban design, this theory suggests that a linear city, at its birth, is highly dependent upon some line of communication, will acknowledge its dependence by a linear form. However,

during growth, nodes or points of interchange will be set up along the line and they too will have to be acknowledged, as there exists a direct relationship between the spacing of nodes and the character of the line of communication. Speed, density, and site conditions are the variables of the urban function that corresponds to the mathematicians'  $L = 2\pi r$ .

The adjacent picture, taken from Fumihoko Maki's book, Investigations in Collective Form, (St. Louis, 1964) illustrates the "urban unduloid" in an ingenious context. Here the nodes are continuous, as the line of transportation has many points of interchange -- each doorstep.



This theory for the linear city becomes important as it effects all urban formats, since a radical-concentric city, is merely a node at the end of a line of transportation; a satellite city, is a node along a route generated by a larger node situated along a larger route; and a scattered plan is merely a juxtaposition of many nodes along intertwining and intersecting lines of transportation. Therefore, for this thesis, from this point, one assumption is made: urban growth is both germinated and generated by transportation.

## Patterns

At this point, a geometry is necessary; not in the sense of form, but of order. In 1800, New York City's surveyor and architect, Joseph Mangin, proposed a plan for the extension of the city to the North. This plan was revised by a committee in 1811 and a rigid gridiron system was laid out over the irregular topography of the city, only retaining one angular street, Broadway. The position of the committee was quite clear: "Straight-sided and right-angled houses are the most cheap to build and the most convenient to live in."<sup>61</sup>

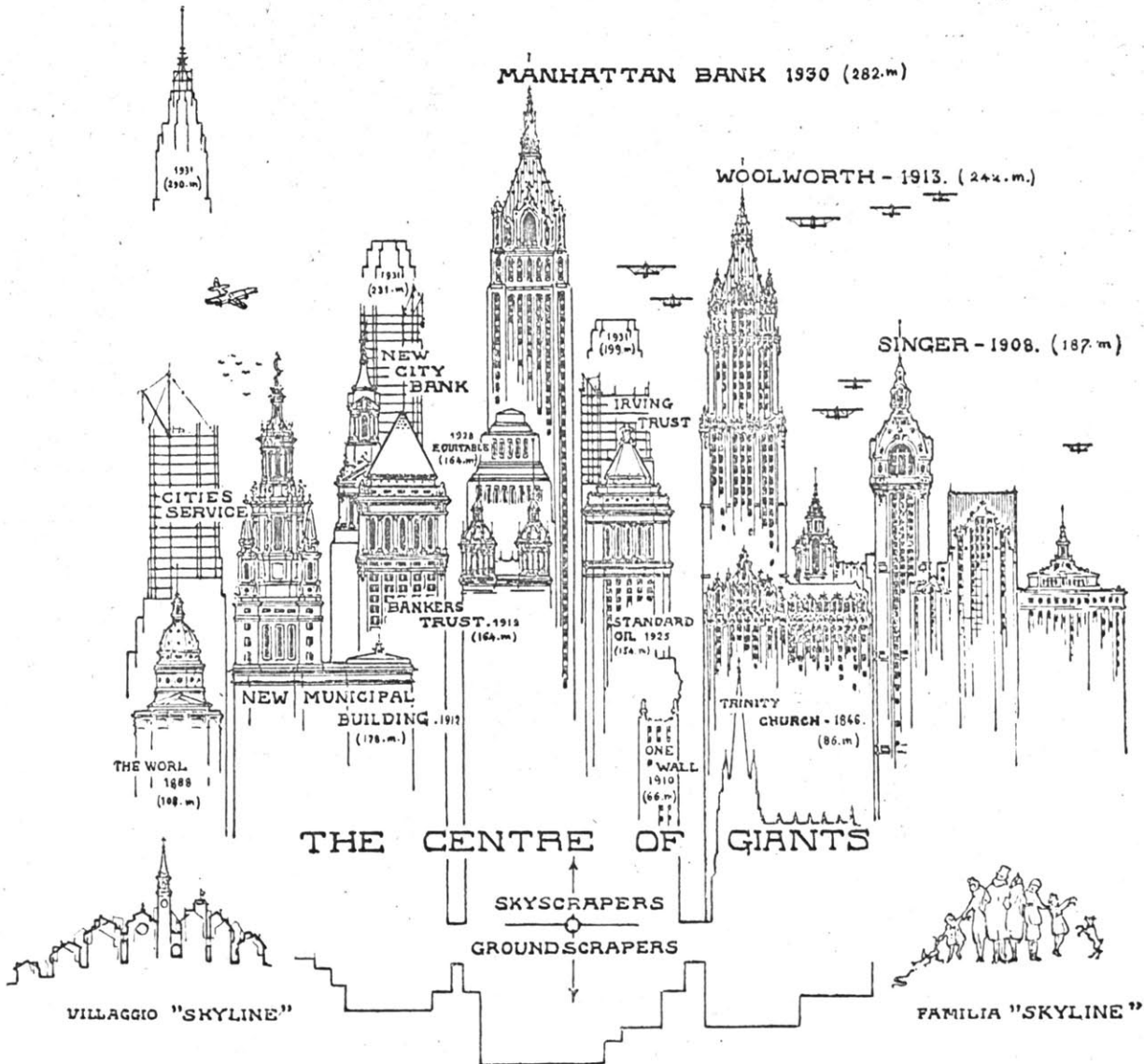
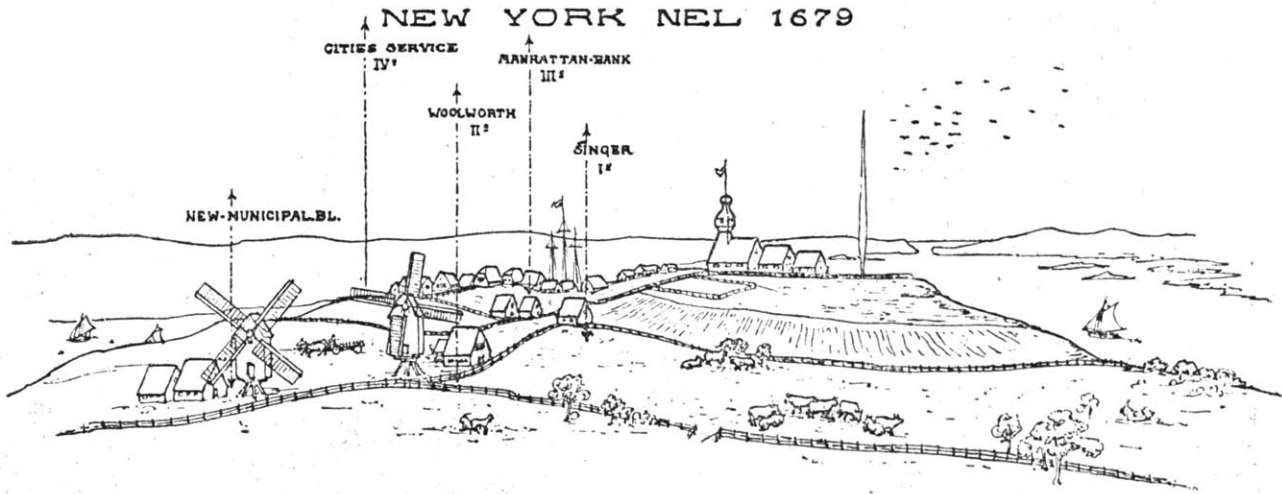
This two dimensional pattern, established over a hundred and fifty years ago, imposes a geometry on the city. It has effected the parts, but not the whole. It is not intended here, however, to judge the effect of the gridiron on city planning, instead, to look at its limitations.

The first obvious limitation, is the lack of different scales within the pattern. There is only one basic size block (with minor variations) that can be subdivided at random. In other words, the geometry of New York, is one that starts at 300 feet by 600 feet (approximately) and stops there. The second problem is that the pattern is two dimensional rather than three, permitting coordina-

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<sup>61</sup> Early Town Planning in New York State, Turpin Bannister,  
(Gallion, Op. Cit.)

# SKYLINE GENESIS



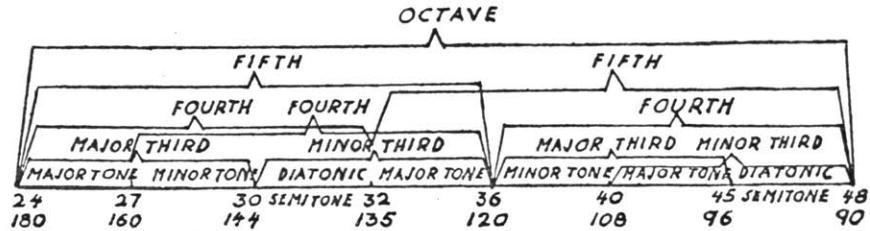
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tion and integration in only one plane. The third problem is growth. Extension is possible, addition is possible, but growth as an organic and natural process that reflects a change in form with a change in size, is not possible.

With New York and its gridiron as scapegoats, it is the intent of the following three sections to take these three problems, answer them, and arrive at the ground work for a system.

### Scales and Series

Assuming that the city does have different scales, they must be related in such a way that it is possible to order them. The coordination of the dimensions of an auditorium with those of



a living room is necessary if the agglomeration is to work as a whole. Bach's well-tempered keyboard offers an excellent analogy, as size, which is frequency in music, and proportion, which is the relationship of one note to the next, is fixed. The octave is not only defined as a fixed 1:2 ratio, but for each key, it has fixed frequencies. C Major, for example, is 128 vibration per second or 256:512 or 512:1024.<sup>62</sup>

A similar series is necessary to relate the different urban dimensions. A great deal of investigation has traditionally been done in this field in a proportional and aesthetic context. The most significant and contemporary research is Le Corbusier's "Modulor".

Le Corbusier's system contains no module, in the ordinary sense of the word. It uses two sequences of dimensions, which are arranged in series, so that each term is the sum of the two

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<sup>62</sup> Ezra D. Ehrenkrantz, Master's of Architecture Thesis, University of Liverpool, 1956, Development of a Three Dimensional Number Pattern.



previous terms. At the same time, each dimension is larger than its preceeder by a ratio that approaches 1:1.618, (the "Golden Mean").<sup>63</sup> This type of series is called a Fibonacci Series, attributed to the Italian monk, Filius Bonacci, who developed the series in the Fourteenth Century.

One of Le Corbusier's series, his "Blue Series," is the standard mathematical representation of a Fibonacci series: 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, ... Much time was spent in attempting to use this sort of series in a three dimensional system, because there exists a great many combinations and permutations within a low number range. But, two problems arose.

First, if you arranged a series of cubes, with dimensions in the Fibonacci series, you arrive at relationships along a diagonal of  $30^{\circ}43'$ , (off the verticle.)<sup>64</sup> (See illustrations and presentation boards.) This bizarre angle becomes a problem in a structural coordination of the parts, as each part, being a cube, requires a  $45^{\circ}$  diagonal for stability and stiffness. In other words, there is an inherent conflict of angles, when a Fibonacci series

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<sup>63</sup> Le Modulor, Le Corbusier, Harvard University Press Edition, Translated by Peter De Francia and Anna Bostock, Cambridge, Massachusetts, 1958.

<sup>64</sup> There has apparently been no work done on the investigation of this angle. During work on this Thesis, it had been known that the angle was neither  $45^{\circ}$  nor  $30^{\circ}$ . Only by chance, looking through trigonometric tables, was it found that  $30^{\circ} 43'$  not only had a cotangent of 1.618, (the Golden Mean), but had a tangent of .618, being the only angle whose tangent equals its cotangent minus 1.

is described in three dimensions. One possible solution would be to relate the volumes in a series rather than the dimensions. However, this in turn forces the cube root of the fibonacci series on each dimension, which makes things worse. A second possible solution would be not to use cubes as the basic element, but rather rectangles whose height to length ratio would be 1:1.618. This could geometrically work, except for the second major problem:



The Fibonacci series, by definition, is an arithmetic series, rather than a geometric one. Since what is added is different for each number, there is no way of deriving one number from any other number except from that which directly precedes it. In a system of different dimensions, any one dimension can only be juxtaposed to a dimension directly above or below it on the scale

(As seen in Model). What this would mean in urban terminology is that, between the scale of the auditorium and the scale of the living room, somehow or another, all the intermediate scales must lie.

Much effort was spent in trying to "salvage" the series, as it had an attribute that made it attractive in terms of a growth system. If squares of the Fibonacci series are drawn forming a rectangle, "the Golden Rectangle", a line can be traced from corner-to-corner that will describe a spiral; mathematically, an Archimedes spiral. This becomes attractive as a growth form in direct relation to nature, as shells, flowers, and horns all involved the Archimedes spiral in their growth form. Nevertheless it was necessary, to abandon the use of this rather unique geometry because of the two problems mentioned above.

Instead, a pure geometric series has been used, applying the simplest relationships possible -- a doubling series. At first, it seemed that the use of such a series would mean the loss of variety and flexibility, though this has hardly turned out to be correct; for, by simply doubling numbers and combining them, an infinite number of variations are possible. Doubling series have been studied (a great deal) in terms of modular coordination. It has been found that, with minor alterations, at one point in the series, a Renard series<sup>65</sup> can be formed that is modified to work

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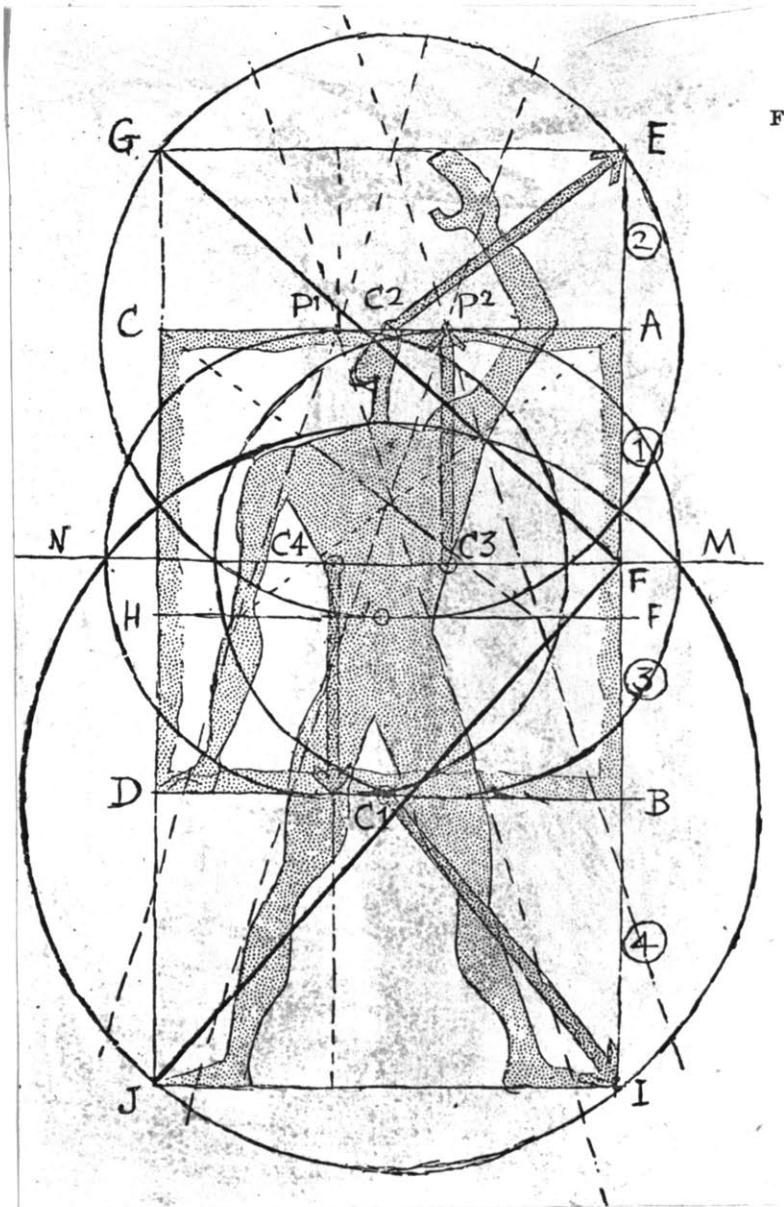
<sup>65</sup> Ehrenkrantz, Op. Cit.

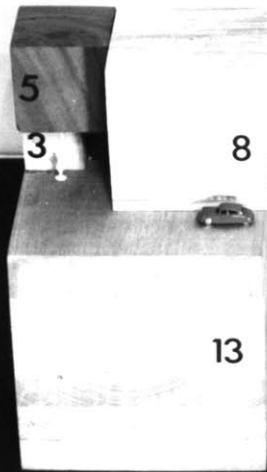
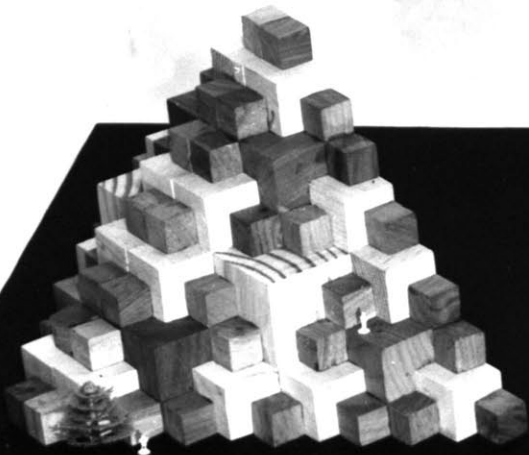
logarithmically. The Renard series is compared below with the doubling series to show the modifications:

Renard Series	1	2	4	8	16	31.5	63	125	250	500	1000
Doubling Series	1	2	4	8	16	32	64	128	256	512	1024

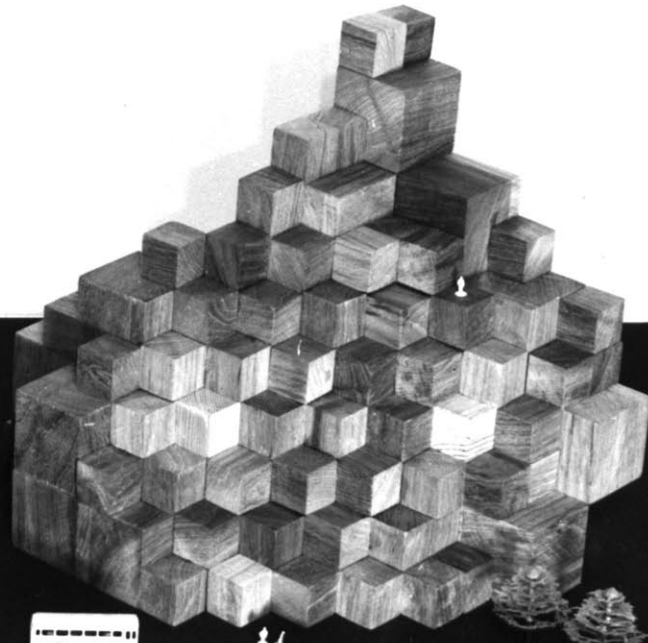
The alterations though, do not prove valid in a system, since the dimensions are purely relative. Associating them with "round numbers" seems unimportant.

Therefore, it has been assumed that the pure Doubling series is the most appropriate.

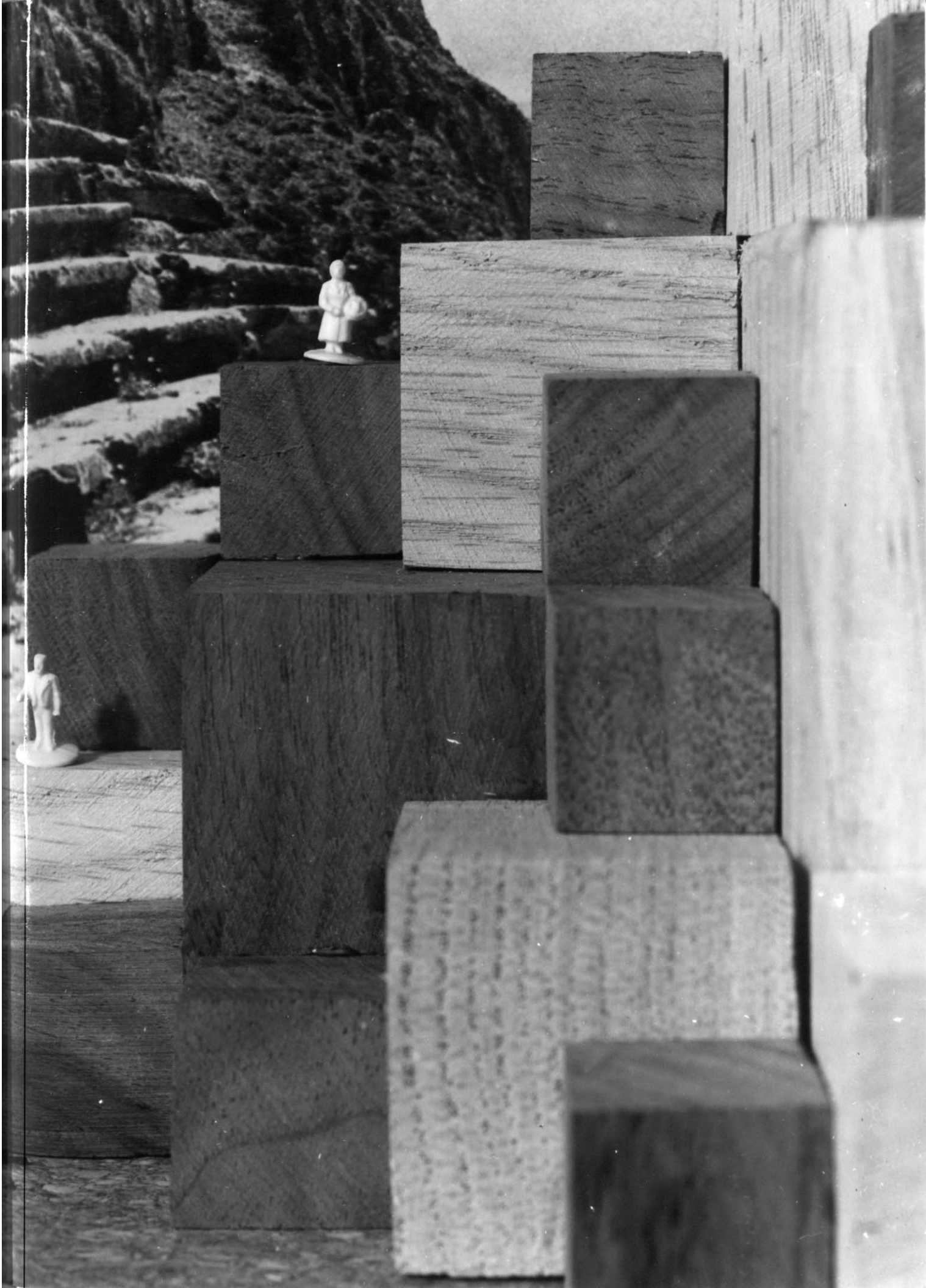


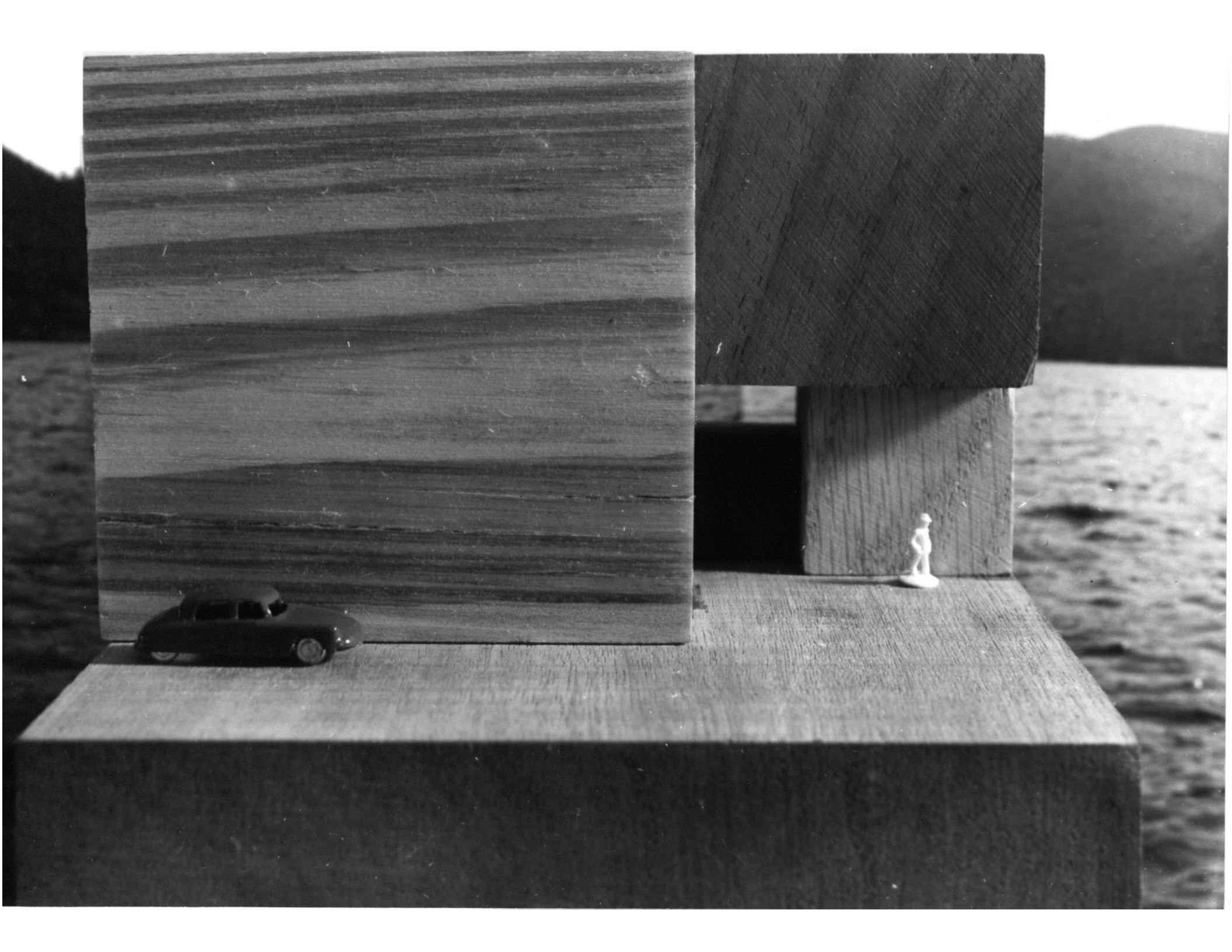


A STUDY OF THE FIBONACCI SERIES  
IN A THREE DIMENSIONAL SYSTEM  
THESIS SEPTEMBER 1965  
NICHOLAS NEGROPONTE



A STUDY OF A DOUBLING SERIES  
IN A THREE DIMENSIONAL SYSTEM  
THESIS SEPTEMBER 1965  
NICHOLAS NEGROPONTE



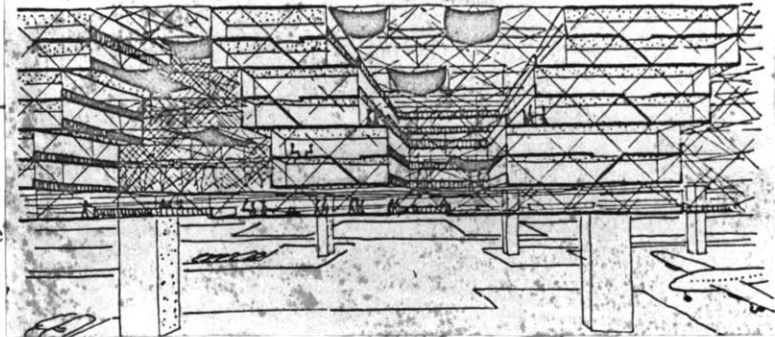


### The Third Dimension

"L'analyse systematique de l'espace, a pour point de depart les cinq corps platoniciens et leurs capacite de juxtaposition. Le seul des cinq polyedres reguliers permettant une division continue de l'espace est le cube."<sup>66</sup>

A city using a three dimensional system, "une cite spaciale," will have to be a "continuous discontinuity," continuous by virtue of the possibilities permitting change, and discontinuous due to the opposition between the parts and the whole. This topic has been studied at length by a French group headed by Yona Friedman, (le Groupe d'Etude d'Architecture Mobile.). Their results have been, however, completely oriented towards form rather than order. Friedman's application of the spacial city consists of a uniform and continuous skeleton elevated on "pilotis," as illustrated on the right.

The skeleton is a many-layered space frame supported every 200-250 ft. As the different levels remain technically and



functionally independent of one another, the planning of the town can be different on any level: "a civic center over an industrial zone,

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<sup>66</sup> Eckhard Schulze-fielitz, "Une Theorie pour l'Occupation de l'espace," Architecture d'Aujourd'hui, 34, February 1963. "A systematic analysis of space, has for a point of departure the five platonic shapes and their capacity to be juxtaposed. The only one of the five regular polyhedrons that permits a continuous division of space is the cube."



habitations over a shopping center."<sup>67</sup>

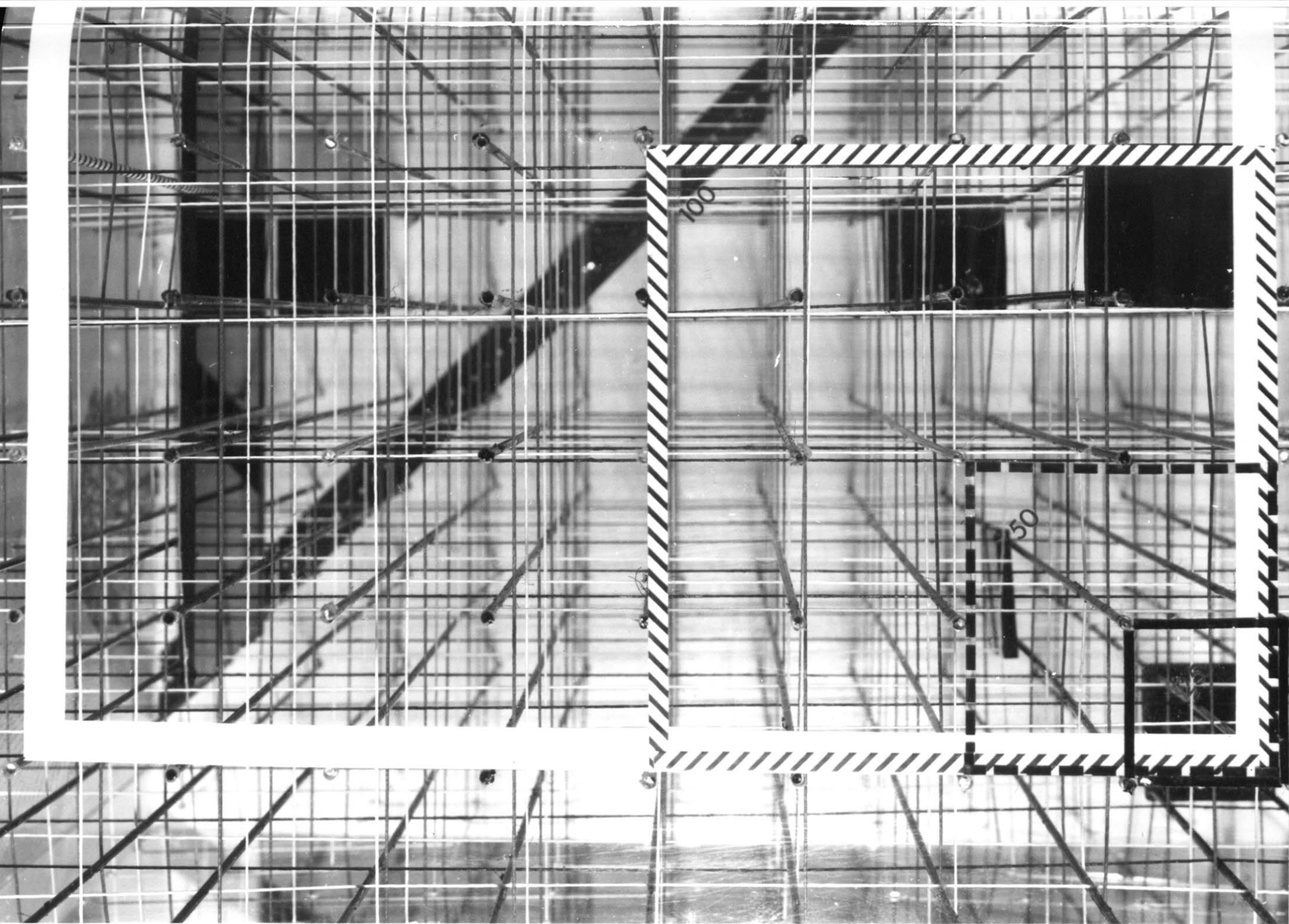
Spacial occupation starts further back from where Yona Friedman presents it. The first problem is describing points in space. This must be done within some Euclidean coordinate system<sup>66</sup> that assumes either a moving or stationary point of reference.

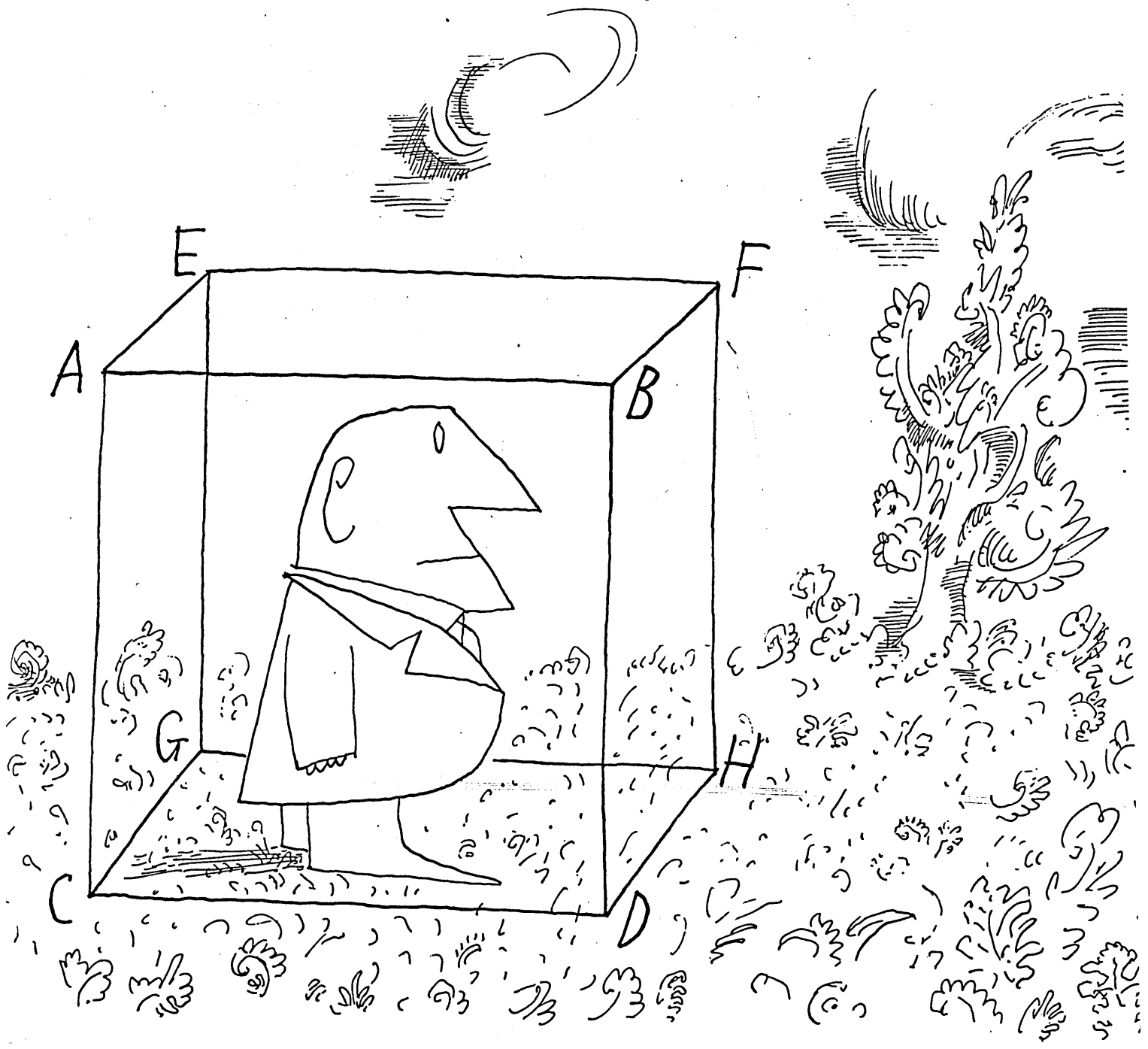
The second problem is to eliminate property rights of the traditional, agricultural sense, and liberate the association of property ownership and ground. Replacing this by describing usable space in three dimensions, within a coordinate system, and allowing for directional projections, in order to protect views, light, and ventilation.

A three dimensional city offers possibilities of very high densities, climatization, flexibility, adaptibility to the terrain, prefabrication, and diversity, if it can grow.

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<sup>67</sup> Progressive Architecture, October 1964, "The Future of Urban Environment," p. 171.





We may go further, and see that the horn or shell, though they belong to the living, are in no sense alive; their growth is not of their own doing, but comes from living cells beneath them . . . and all alike, consist of stuff secreted or deposited by living cells; all grow, as an edifice grows, by acceleration of accumulated material; and in all alike the parts once formed remain in being.<sup>68</sup>

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<sup>68</sup> Thompson, Op. Cit.

## Growth

Nature adds material only where needed. This elementary principle must be adhered to in urban growth, as we cannot keep overstructuring our cities, in anticipation of some preconception that will either never arrive or soon be passed. Physically, this has a simple answer which is not fantasy due to our advanced technology. All new material has to be added to the bottom, as in the shell, increasing in such a way that each increment only accounts for what "is there" rather than what "will or might be there".

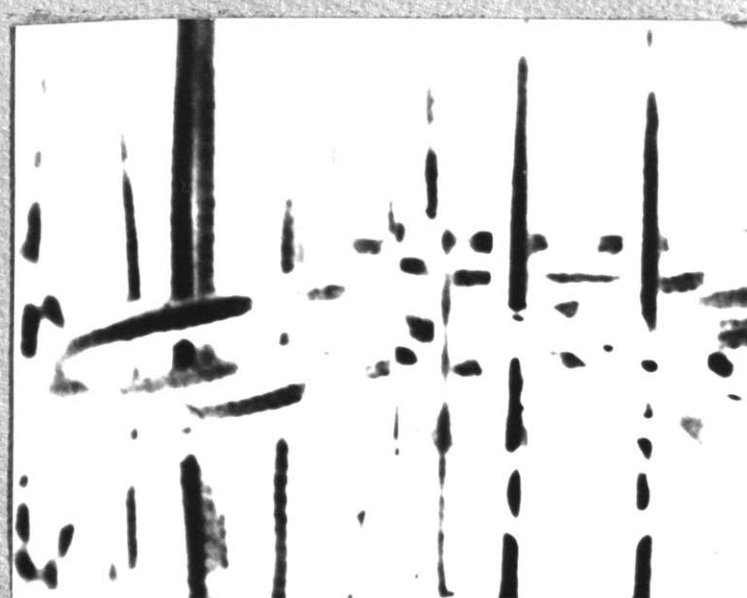
Mechanically this means jacking up elements and building below, always on ground level. This must occur, however, within the proper scale -- "the scale of growth." Thus, there still remains "the scale of adaptability", which is separated from the growth process to assure diversity, flexibility, and changeability. In other words, there are two scales. The mega-scale, where growth takes place, and the micro-scale, where adapting to specific functions occurs.

This principle acts as the most important design criteria throughout the thesis. (It is best illustrated in a movie that accompanies the presentation.) It establishes a structural growth process that can work within the system. However, it says nothing about the functional growth process of a city. It does not establish the facilities incorporated at different intervals of growth, as

these functional characteristics are what make up form -- the image of the city.



Chapter four: Mechanics



## MECHANICS

### Introduction

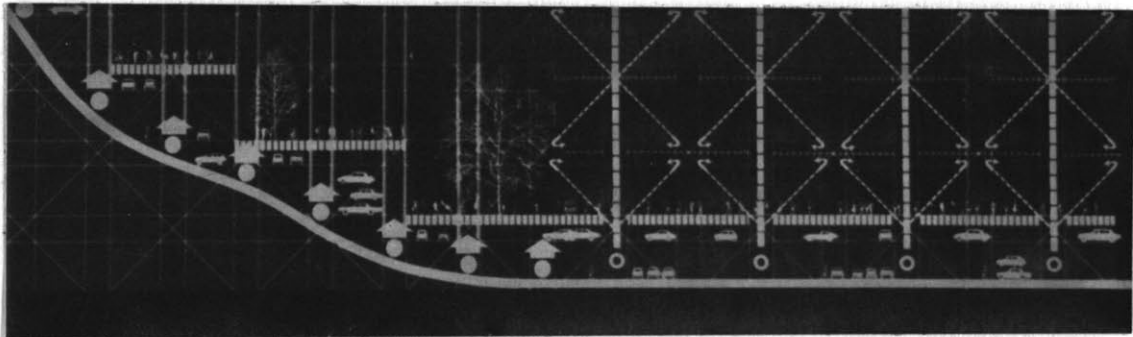
The jump from a theoretical order to a physical system is via the design process. This occurs over a long period of time, involving judgements, decisions, and corrections. The aim of this chapter is not to iterate the design process; but rather to describe the stage at which this research was terminated with a system of urban growth. The system of growth presented in the following chapter is neither the city of the future nor the answer to urban growth. It is merely a description of a phase of a much larger whole, opening many questions for future stages.

In order to follow the standard thesis format, "phase two" covers the overall system and "phase three" deals with the structural problems, jointing, and mechanical integration. However, no attempt has been made in this chapter to separate the two phases because of the vast feed-back process that has occurred throughout. In the drawings, though, the last panel is concerned solely with stage three, (see illustration at the rear of report.)



### The Urban Piano Nobile

A point of departure is necessary to establish a three dimensional system, a point that will be common to all stages of growth. The ground is a logical common denominator, but it too must be ordered and defined. The system establishes an urban piano nobile that acts as a matrix for the city: urban life above and the urban "engine room," below.



Above the piano nobile is the city. Below are the energy cells. The mechanical growth process, utilities and vehicular storage all occur in this interspace. A new stationary ground level is created, and above that, moving ground levels can exist. Standard floor-area ratios can no longer be applied, as two acres of "ground level" may easily occur over one acre of land, after a certain height.

The piano nobile would follow the natural topography, span rivers, and even project onto water. The height, the function, and

spans of this level would always be dependent on the site conditions, thus requiring as flexible a "piano nobile" as possible.

### A Three Dimensional "Mova-grid"

The standard Hippodomic plan of the Hellenic Period involved laying a square grid over irregular topography. This simple system has been revived many times, provoking the natural criticism that the method does not acknowledge any environment conditions. This criticism would not be applicable though, if the system were three dimensional and composed of a fine enough fabric. For a system of growth, a three dimensional grid, of two sizes, has been chosen: 10' ... 20' ... 10' ... 20' etc ... Such small units can easily follow the topography and generate, in their accumulation, any form forced by site conditions.

This fine grid merely defines points in space, essentially, surveying the air. Each point becomes a potential element of the city and its nature is further defined, in terms of structural and mechanical criteria, by a larger grid system: a sixty foot grid, defining a mechanical zone for the supply and return of utilities and a structural zone for bracing. This second grid is further delineated by an even larger grid, the "mega-grid," 500 feet on center.

The primary grid, 10' ... 20' ... 10', exists throughout the system and marks all the possible intersections of vertical, horizontal and bracing members that are structural. Specifically, in

the horizontal plane, the grid defines all the potential columns, at this small spacing, but the location of a column within the system at any certain place.

As growth has partially been defined as adding material only where needed -- involving a jacking process -- it is the columns that are the primary members in the mechanical growth process. The forward-looking nature of jacking up an entire city might seem fantastic, even though the procedure is the most logical. Jacking up columns promotes problems of passing, timing, foundations, and lifting; but permits an organic growth within a moving co-ordinate system, the "mova-grid."<sup>68</sup>

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<sup>68</sup> This is best illustrated in the first section of the visual presentation, illustrated at the rear of this report, and by a movie that accompanies this thesis.

## The Mega-grid

This highest order of grid, 500 feet on center, is the major organizing element for the mova-grid. As in the finer grid-work, the larger grid merely defines points in space that in turn describe potential volumes. Unlike the mova-grid, the mega-grid does not move along a co-ordinate system, but circumscribes a volume 500' by 500' by 'X' feet high, a mega-block.

Within the mega-block there are certain criteria that must be adhered to:

1. Passing only occurs with disconnected bodies within a mega-block, or between two bodies, each in a different mega-block.
2. Two bodies must be "in phase"<sup>69</sup> and lie within the same mega-block, in order to be connected.
3. The highest point in the mega-block establishes the first floor, thus floors have to be labeled in reverse of the traditional method.
4. Each mega-block would have a primary and secondary orientation. These orientations would demand certain projections of open space in relation to the site conditions. 70

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<sup>69</sup> The phasing of units is mostly a mechanical and structural co-ordination and is best illustrated photographically.

<sup>70</sup> This type of criteria is the beginnings of a much larger subject, "volume-use," which, in this case, would be a study of solid to void ratios at all scales.

5. Between each mega-block would exist an interspace that would act as a circulatory diaphragm.

The above manifesto is the beginning of an organization of three dimensional, moving units. The primary goal is to make a strictly ordered system without affecting flexibility and diversity. The mega-block itself is large enough to not affect flexibility and diversity; the above criteria concern primarily timing and phasing.

## Mechanical Grid

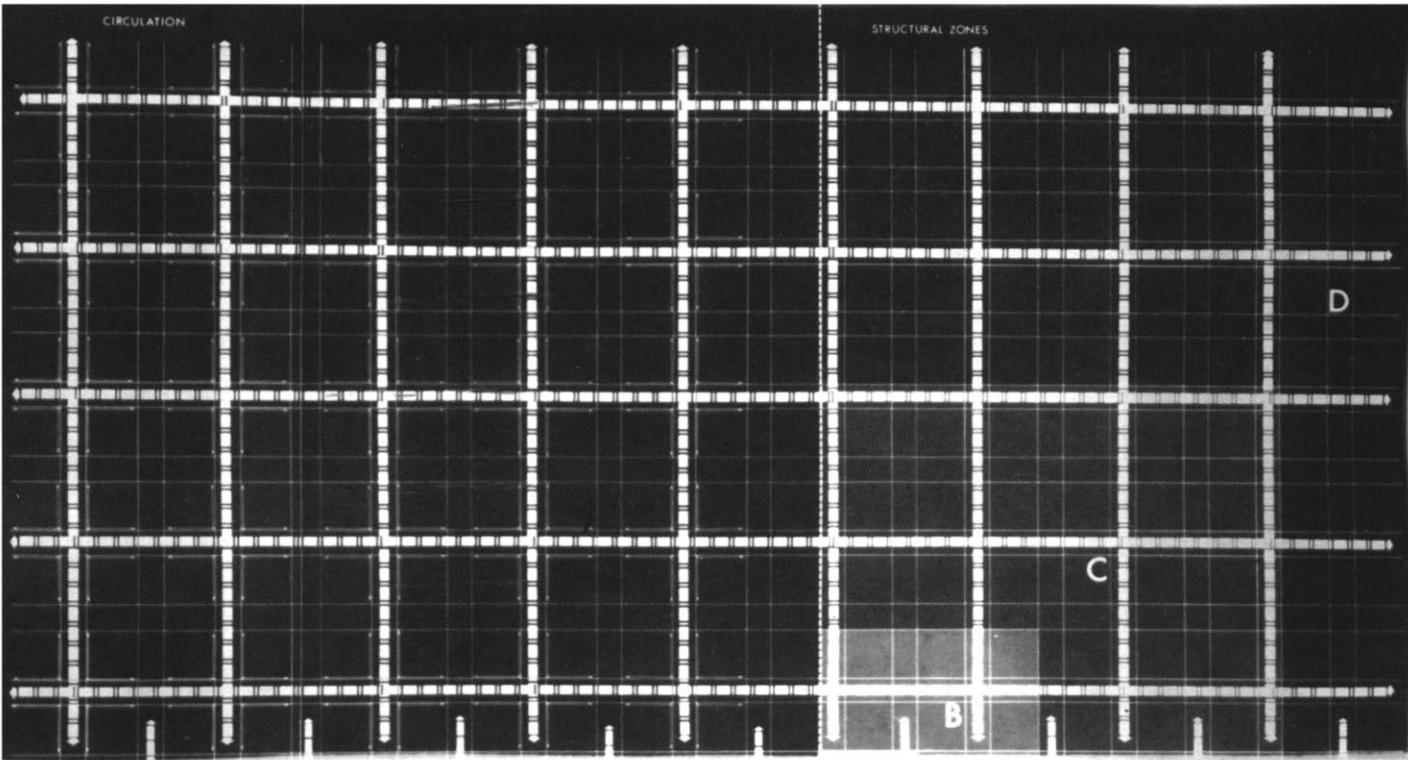
This third and last three dimensional grid describes potential lines rather than points. The system is designed in anticipation of a great deal of centralization of utilities in order to take advantage of nuclear energy sources. These lines of mechanical service have been designed to be extremely large if necessary, because a great deal more mechanical services will be supplied by the city in the future. If an urban fabric is structured accordingly, not only will telephone, gas, steam, water, and electricity be piped throughout the system, but also disposal ducts, vacuum lines,<sup>71</sup> mail pipes, delivery shutes, and all sorts of computer services will be an integral part of the mechanics system.

The mechanical system is broken down into primary, secondary, and tertiary (distributory) routes along a sixty foot grid. Superimposed on the mova-grid, the mechanical grid imposes a system of: 10' mechanical ... 20' ... 10' ... 20' ... 10' mechanical ... 20' etc ... At the corners of the mechanical grid is the primary mechanical circulation, integrated into the vertical members, (potentially an area as large as ten feet square). The secondary circulation occurs along the diagonals and can be by-passed. Its

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Milo Hasting's method of linear community planning, for which he received a prize from the American Institute of Architects in 1919, consisted of houses attached at the rear to their street and faced on to inner parks. The service streets were to provide all manner of modern conveniences, including piped vacuum for cleaning. (Journal of the American Institute of Architects)





inclusion is primarily to reduce the maximum probable length of the distributory system. The tertiary system lies along the horizontals, and is solely a distributory system.

STRUCTURAL AND MECHANICAL MANIFESTO

1. Three dimensional "mega-grid" defines all potential joints, horizontal members, vertical members, and diagonals.
2. All horizontal members are simple spans.
3. All vertical members and diagonals carry no moments.
4. All diagonals are  $45^{\circ}$ .
5. All jacking occurs on vertical members.
6. Double lines of diagonals are potentially 60 feet on center.
7. Vertical members and diagonals are designed for maximum probable load.
8. Horizontal members are designed for specific loads; detailed so as to be easily strengthened.
9. Vertical members, diagonals, and horizontal members carry respectively primary, secondary, and tertiary mechanical systems.
10. Long span sections are a function of the load above (always known) within the following ranges:
  - Zone A: 20' to 50', section depth 2'
  - Zone B: 30' to 200', section depth 10'
  - Zone C: up to 400', section depth 20'
  - Zone D: up to 500', section depth 30'

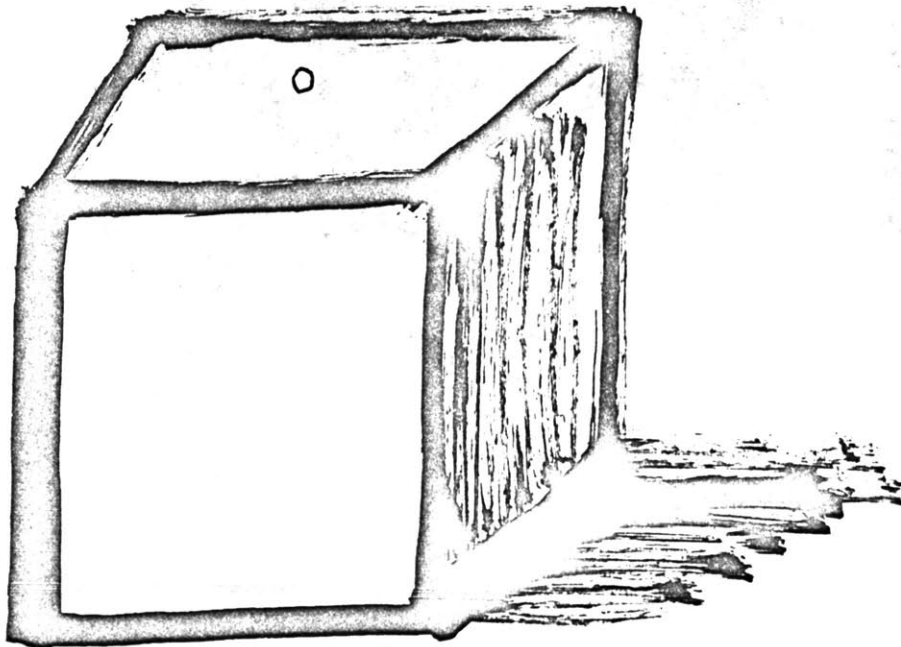
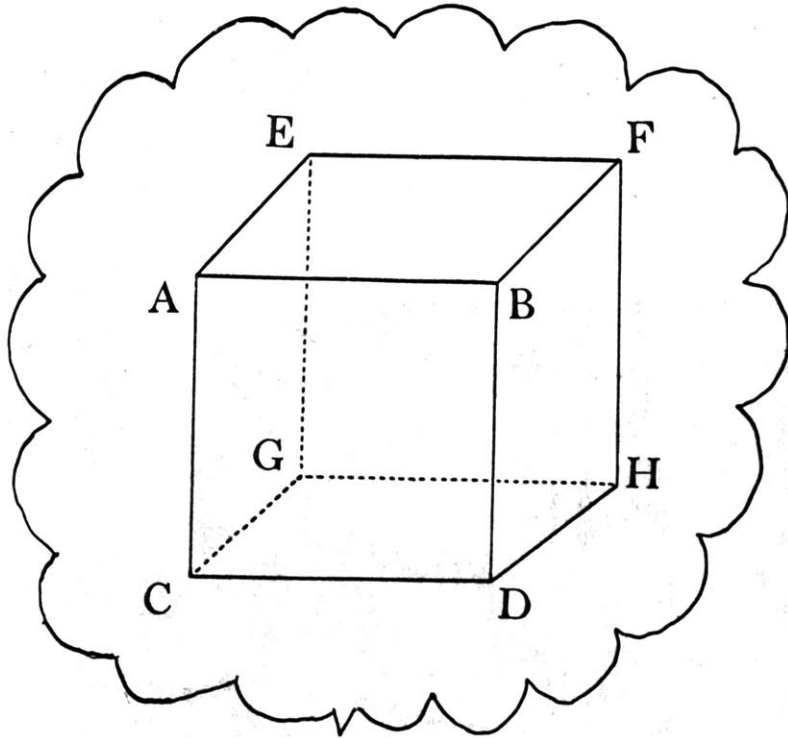
## Structural Components

The structural components of the system are the crucial ones, as they are the parts that have to follow the three dimensional grid. On the preceding page is a structural and mechanical manifesto for the system.

Rule one has been discussed.

Rule two, seems equivocal, as a simple span is much less structurally efficient than a continuous span. However, by requiring all horizontals to be simple spans, a more complete flexibility is possible. In this way, live and dead loads can be changed at any point in the system without inflicting stress alterations on any other point. The rule also reflects itself in Rule three, as only by having simple spans can the verticals be free of any moments. In order to facilitate the jacking process, it is necessary to keep the columns moment-free by always having pin joints at the ground level. Extended, Rule three means that all diagonals and verticals will be composed of closed structural sections, and cannot be locally loaded.

Rule four, is more a problem of geometry than structure. The diagonals do not necessarily have to be closed-section structural members spanning at  $45^{\circ}$ . The bracing, though, whether it is a closed section, shear wall, or moment resistant frame, must lie within a square.

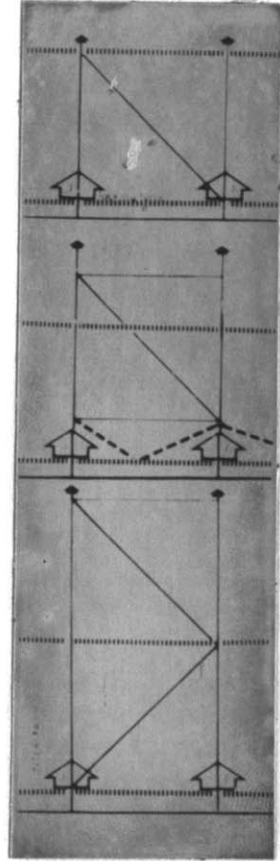


Rule five, permits all jacking to be vertical, which facilitates the complex job of lifting. Temporary bracing is necessary during the jacking process and diagonals are only installed when the lifting reaches a point where the diagonal is a complete member spanning simply between two points. (This all occurs in the interspace between the piano nobile and the ground level.)

Rule six, has been discussed.

Rule seven, exists because it is more economical to carry pure tension and compression -- especially when the members are laterally supported at least every twenty feet. In detail, this has been designed as a hollow column 16 inches square with a constant outside dimension and an increasing wall thickness to permit a constant column size throughout almost the whole system that will never have to be strengthened.

Rule eight, on the other hand, is opposite for the horizontal members, as they support bending which is not economical to carry. At the same time, it is not difficult to add plates to a beam, and even to subtract if necessary. Therefore, the rule is merely of economics and, combined with rule seven, seems to be efficient.



Rule nine, has been explained.

Rule ten has not been derived through mathematics, but through a great deal of structural consultations. The great overlapping of dimensions is due to the different loading conditions that are possible depending on the height of the system. Also, since all beams are simple spans, a high depth to span ratio has been created to overcome some of the inefficiencies of simple spanning. In each case the size member fits into the mova-grid system, which is the primary concern.

## The Jacking Process

At one stage, it was felt the jacking process ought to be "phase three" of this thesis. This process, however, has not been made the basis for "phase three" for two reasons. First, there is no precedent at which to look and research for such a project would be a thesis in itself. Secondly, it is of the opinions of Professors Waclaw Zalewski, Eliau Traum, and Leon Groisser, that such jacking is completely possible. The usual problem is never deadload, but bracing. Nevertheless, this section will deal with the jacking process diagrammatically.

Assuming force and energy to be unlimited<sup>72</sup>, there remain four basic problems: timing, reclaiming jacks, foundations, and aligning mechanical circulation. The first problem is a computer problem. It is necessary to have every point within the mega-block start rising at the same time and move at the same rate in order to avoid inducing stresses into the system. This would have to be a computer regulated observation, as tolerances as low as a sixteenth or thirty second of an inch might be necessary.

Reclaiming jacks is a problem of detailing so that the jacks could lift without interfering with the butting of the next column section. This would require strong shear plates to transmit the load a few inches to either side of the column. (See diagram.)

Foundations would be the trickiest problem, as the foundation

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<sup>72</sup> "Give me a place to stand and I can move the world," Archimedes of Syracuse, from: Pliny, Natural History.

loads are always increasing or, in some cases, might drop off to zero. This would require a system of precast foundations that can be added and removed according to load. There would be a point, however, where the load throughout the system would demand an entire mat of foundation work below the city. It would be better to avoid pile driving, though this would be dependent upon site conditions. If necessary, though, all pile driving would have to occur below the "piano nobile" and not interfere with urban life.



## Next Stages

Since there is no insinuation of the total solution in this thesis, as an epilogue, this section intends to point out a few of the many questions raised that could act as next stages in the same subject. The psychological, economic and political implications are vast and not divorced from architecture. But, solely in the realm of architecture, there are many problems unexamined by this thesis.

One would be a thorough study of solid to void ratios. A re-evaluation of land use in terms of three dimensions, to establish limits in height, density and land use

Afterwards, a second would be to apply the total system to an actual site with as much of the usual city planning information as possible: desire lines, population distribution, commercial and industrial distribution, transportation, and rates of growth. In this way, the system could be tested as a generator of form -- growth form.

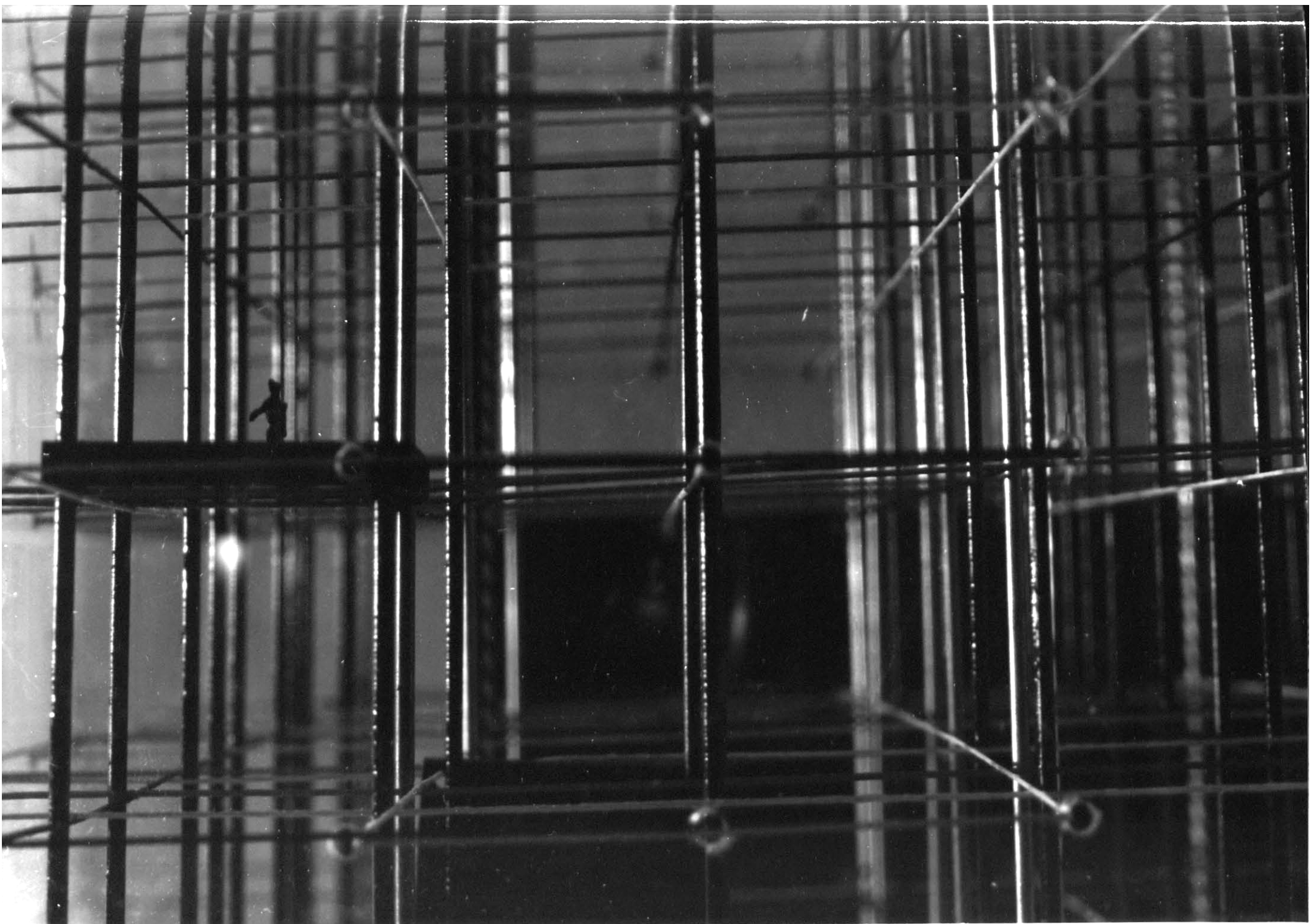
The aligning of mechanical circulation would involve a jointing problem with flexible sections that can be used during the lifting operation and rigid section that could be installed afterwards. Elevators would be the most difficult to incorporate in the lifting process and would have to be either connected with moving lobby areas or not used during the actual period of movement, (which

for the most part would occur at the "odd" hours.)

The most severe problem with jacking would probably not be mechanical but psychological. There would be the problem of address, identification, and the constantly changing image of the city. In August, you might be taking the elevator three floors down to get to the shopping center located in the next mega-block. Whereas, in December, you might have to ride one floor up to get to the same shopping area. The implications of such a physically changing environment are naturally unknown, as we have never experienced such conditions. This sort of study might well be one of the next stages.

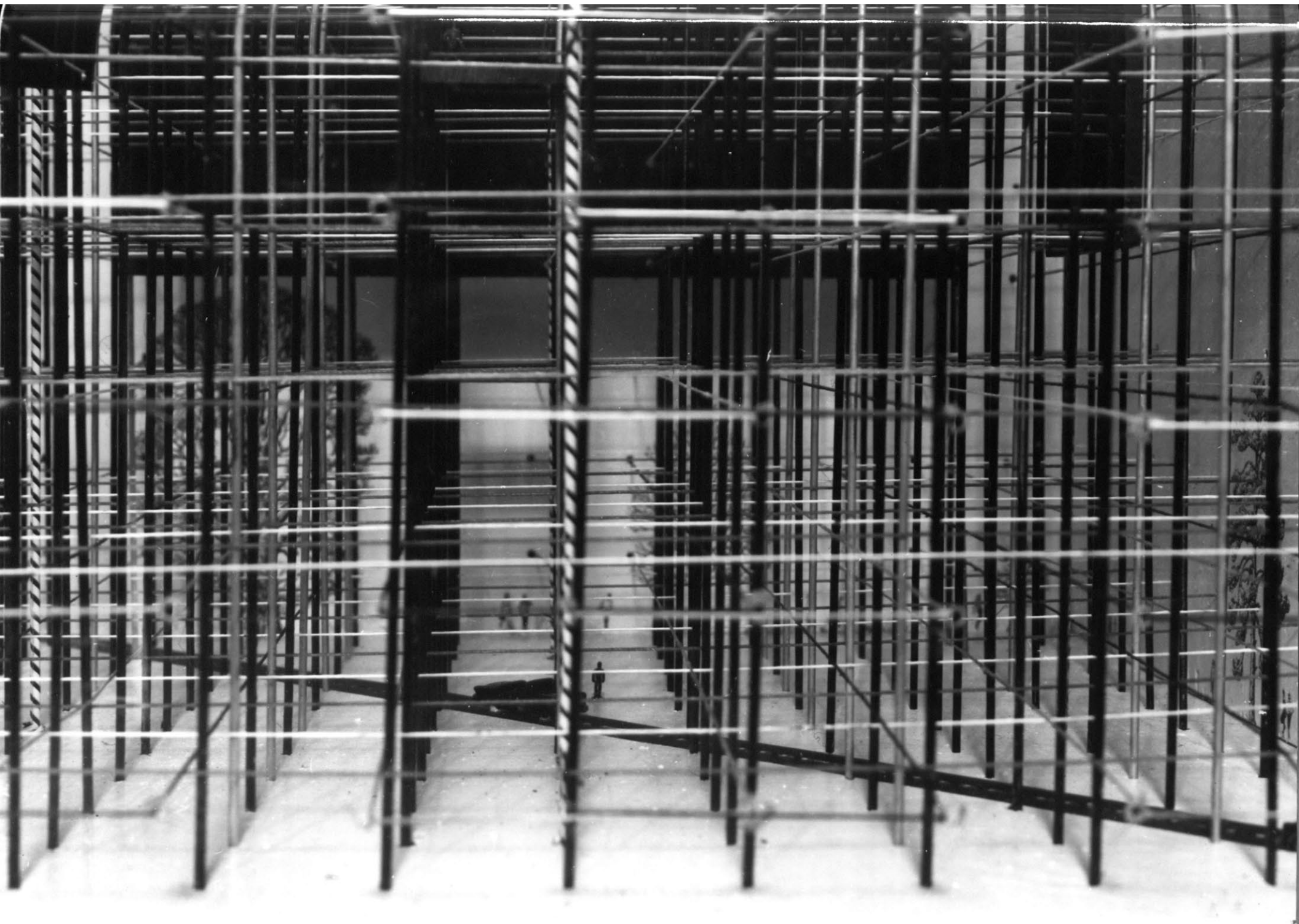
"If indeed the world in which we live has been produced  
in accordance with a plan, we shall have to reckon  
Nero a Saint in comparison with the author of the Plan. "















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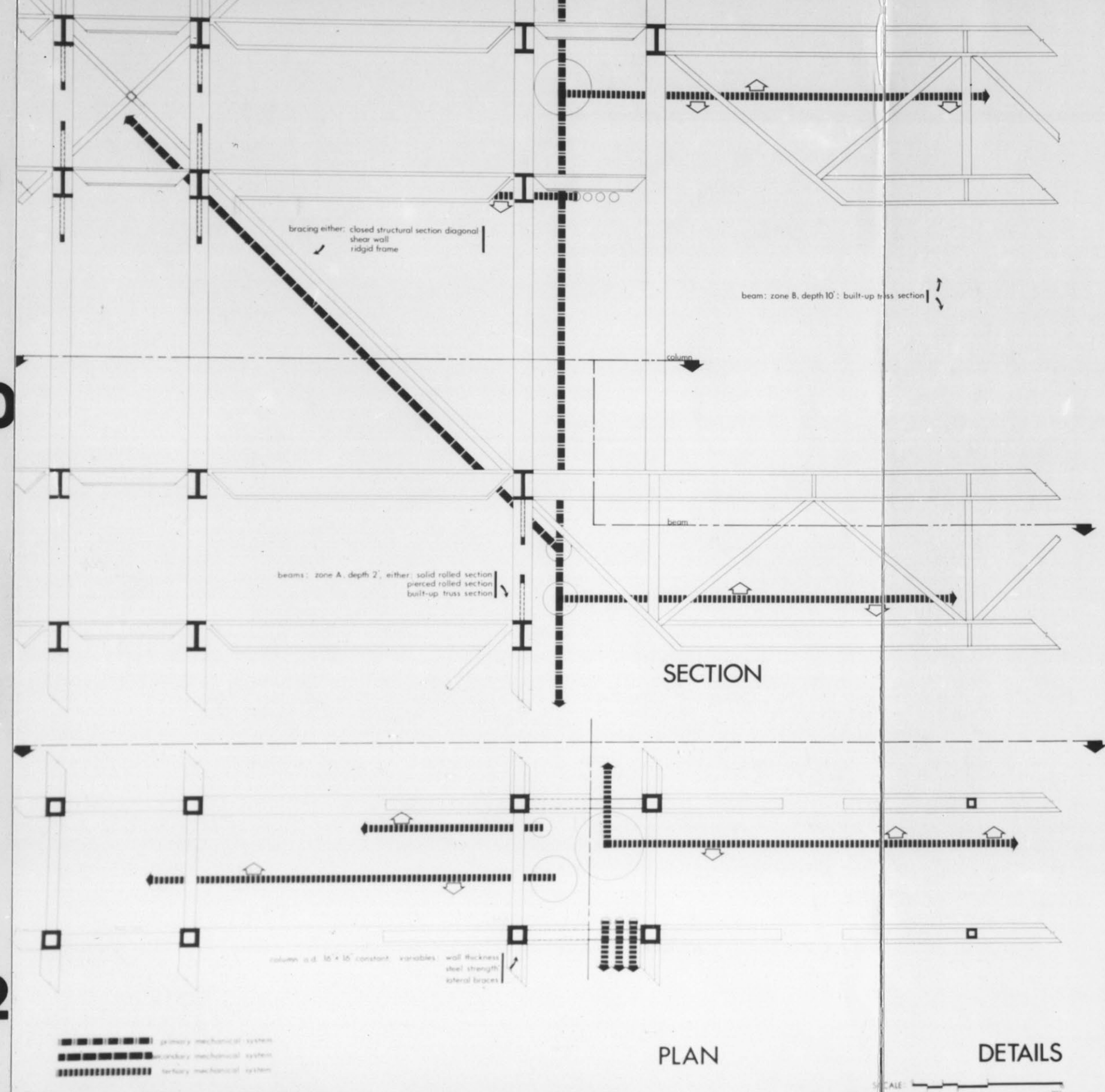
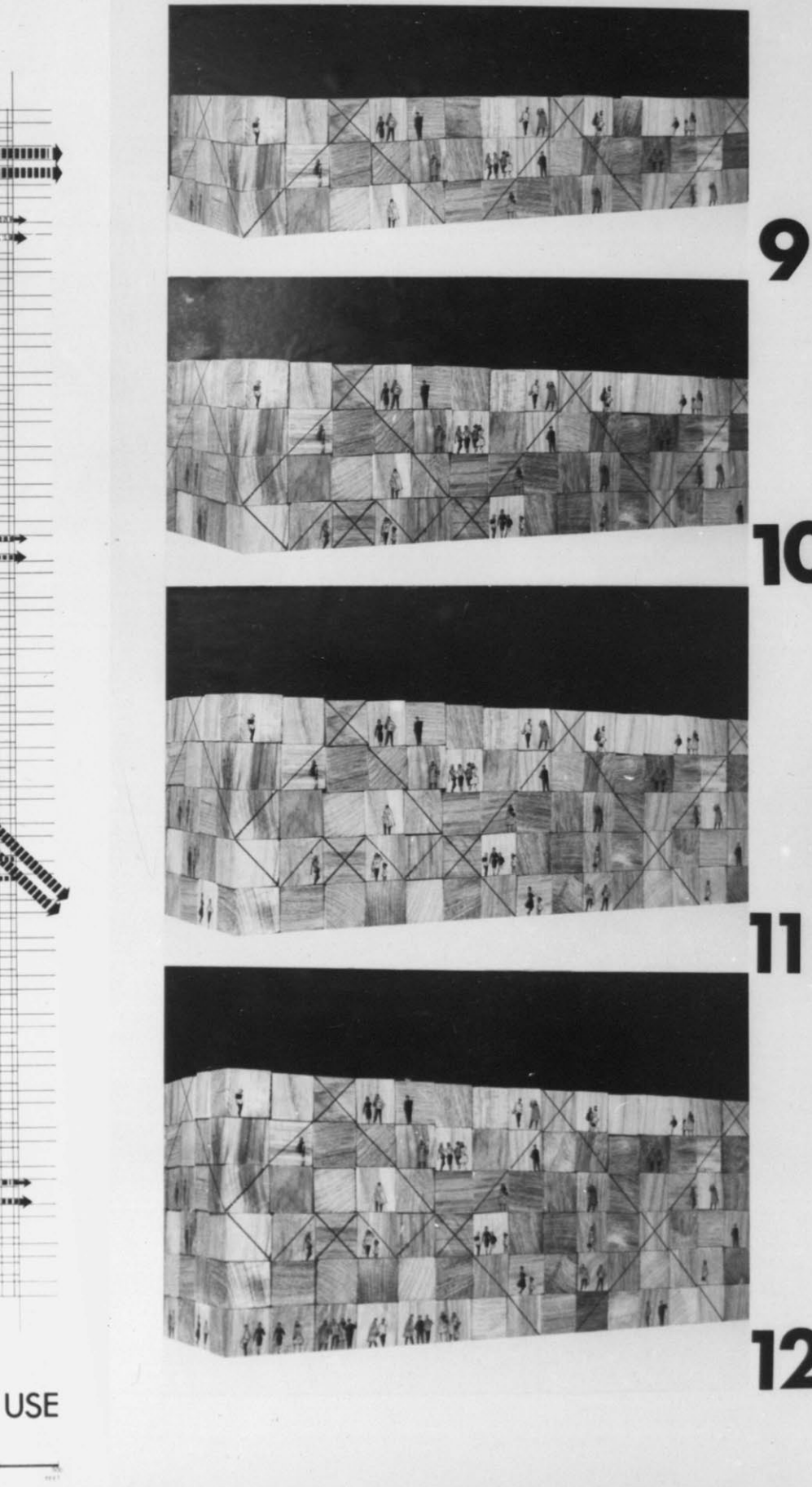
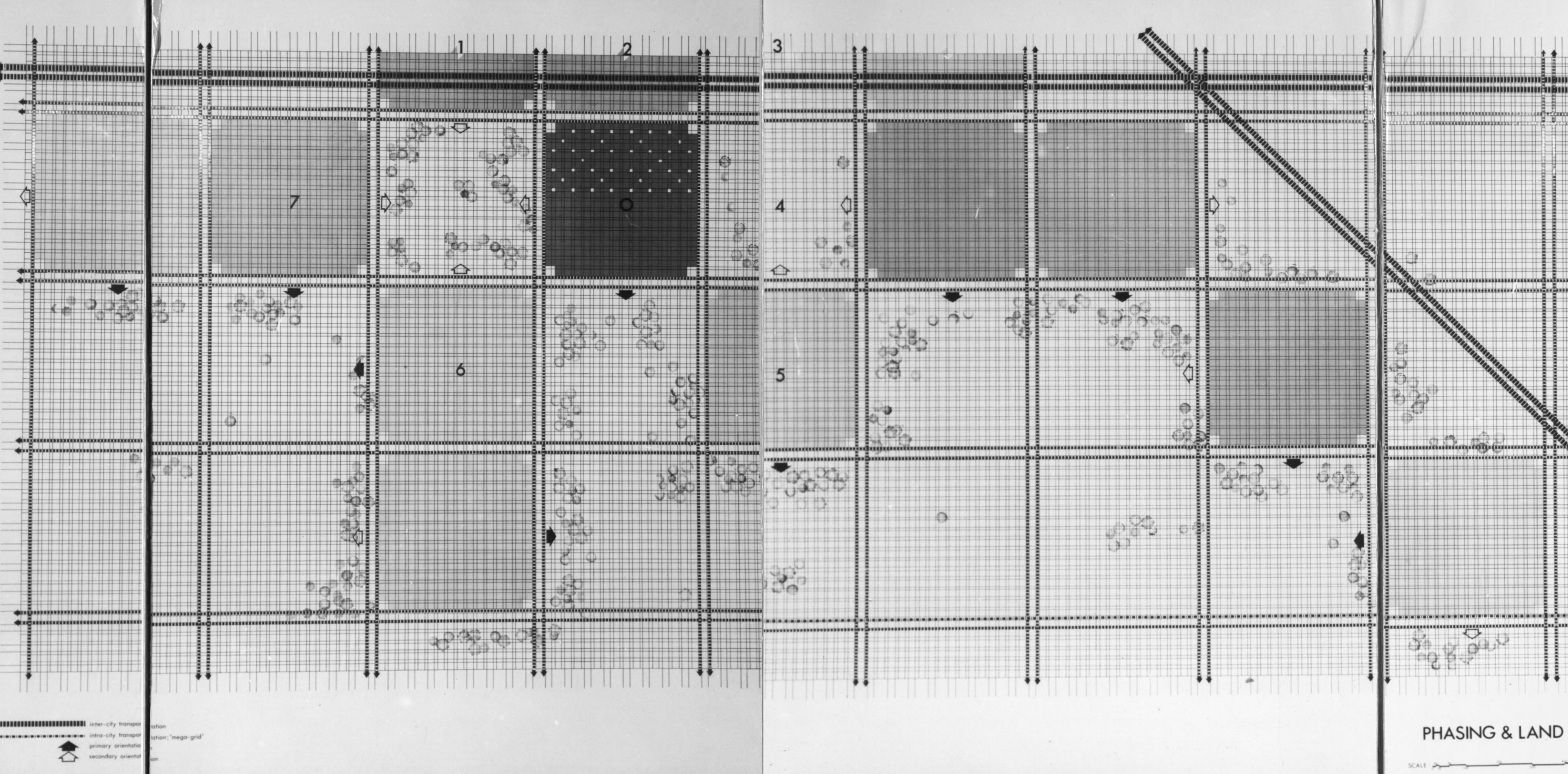
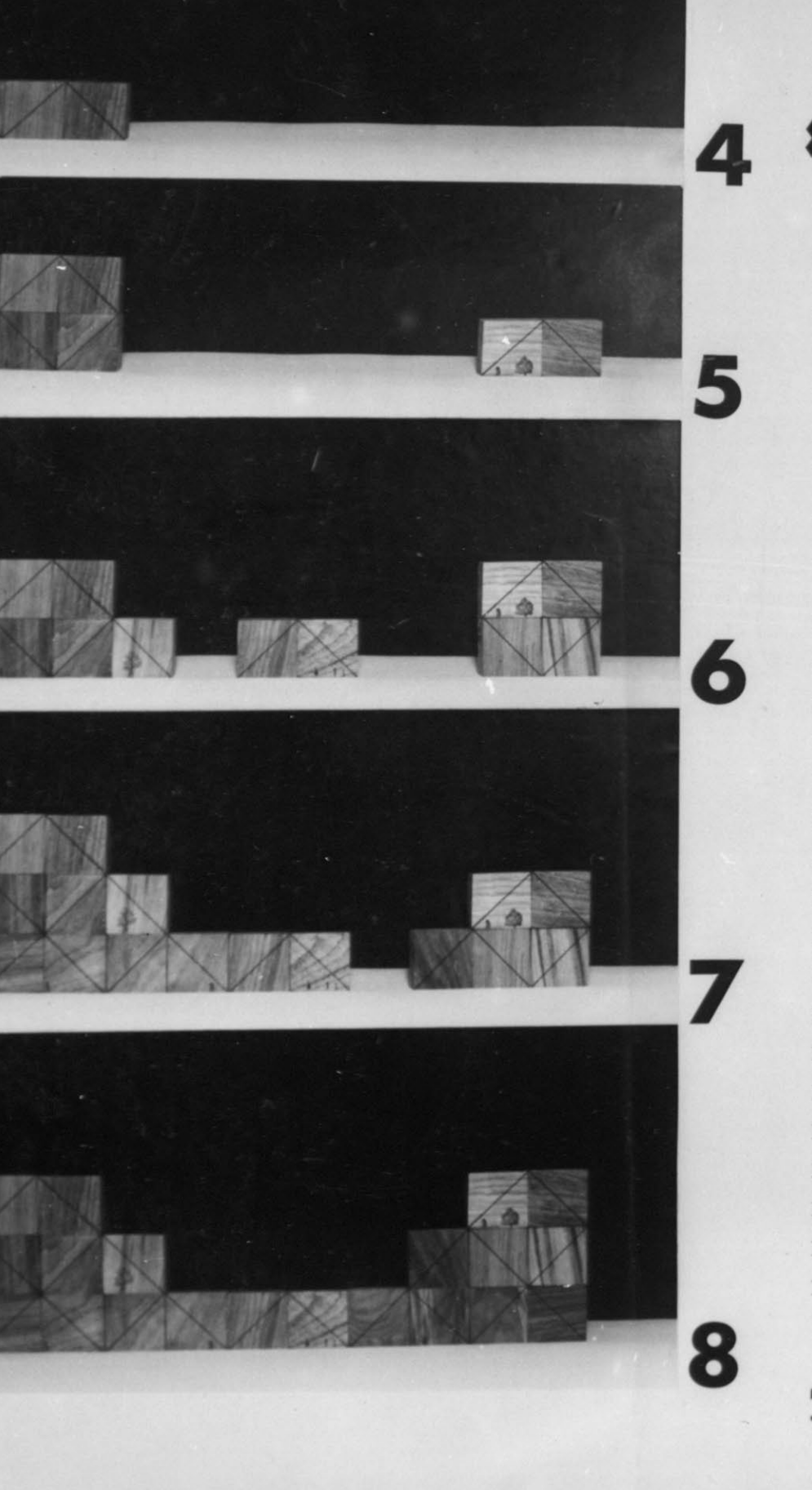
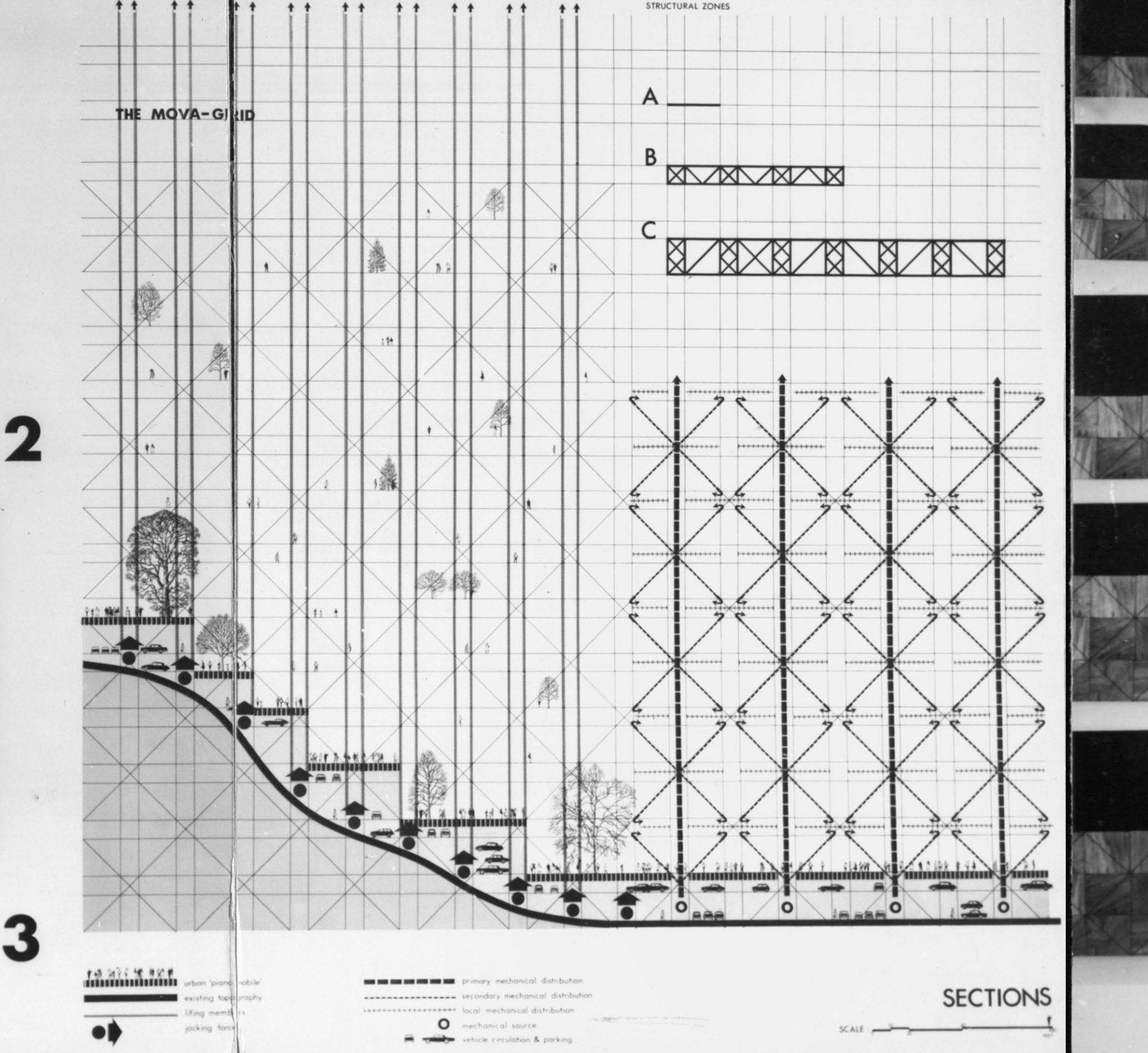
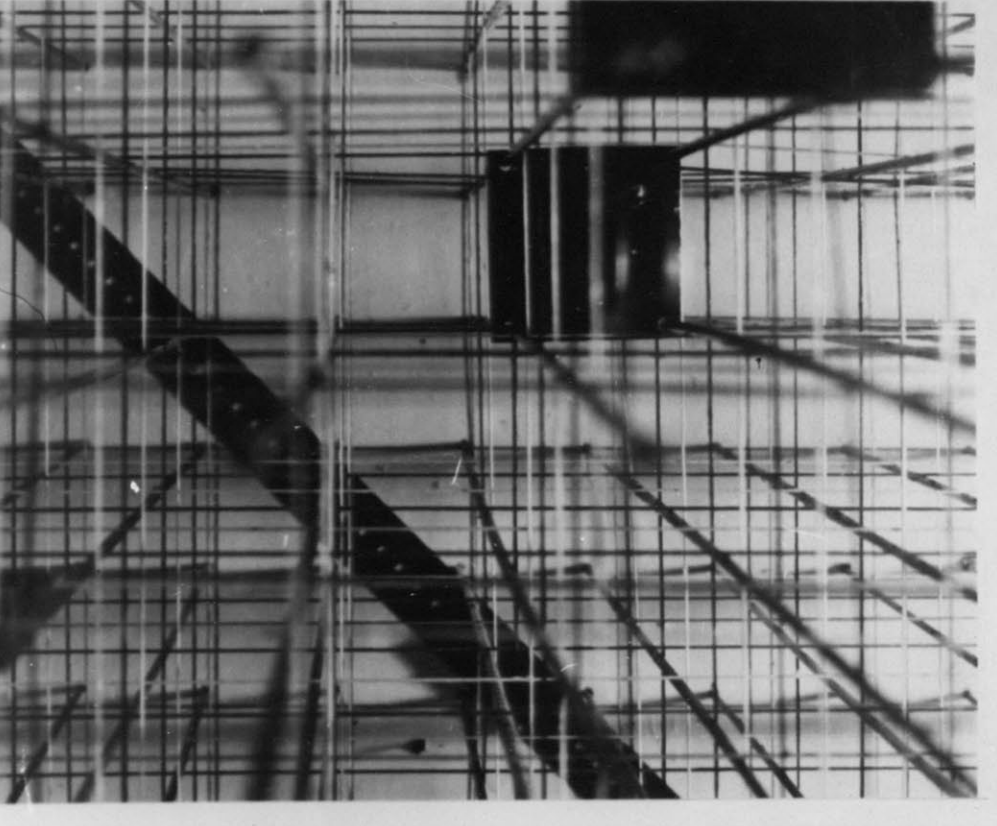
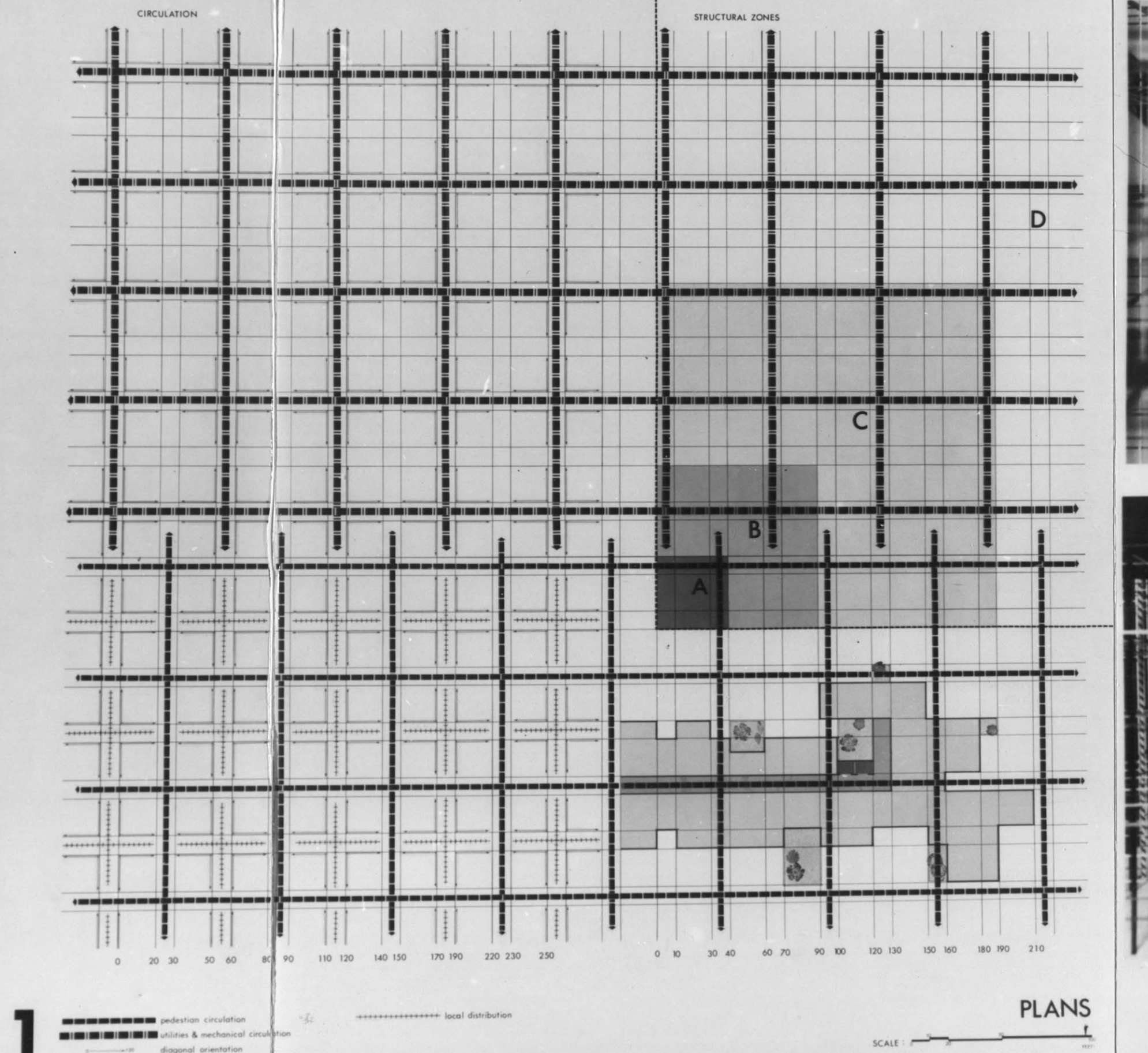
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**STRUCTURAL & MECHANICAL MANIFESTO**

- THREE DIMENSIONAL "MEGA-GRID" DEFINES ALL POTENTIAL JOINTS, HORIZONTAL MEMBERS, VERTICAL MEMBERS AND DIAGONALS.
- ALL HORIZONTAL MEMBERS ARE SIMPLE SPANS.
- ALL VERTICAL MEMBERS AND DIAGONALS CARRY NO MOMENTS.
- ALL DIAGONALS ARE 45°.
- JACKING OCCURS ON VERTICAL MEMBERS.
- DOUBLE LINES OF DIAGONALS POTENTIALLY ARE 60 FEET ON CENTER.
- VERTICAL MEMBERS AND DIAGONALS ARE DESIGNED FOR MAXIMUM PROBABLE LOAD.
- HORIZONTAL MEMBERS ARE DESIGNED FOR SPECIFIC LOADS, DETAILED SO AS TO BE EASILY STRENGTHENED.
- VERTICAL MEMBERS, DIAGONALS, AND HORIZONTAL MEMBERS CARRY RESPECTIVELY PRIMARY, SECONDARY AND TERTIARY MECHANICAL SYSTEMS.
- LONG SPAN STRUCTURAL SECTIONS ARE A FUNCTION OF THE LOAD ABOVE (ALWAYS KNOWN) WITHIN THE FOLLOWING RANGES:
  - ZONE A - 20' to 50'
  - B - 30' to 200'
  - C - up to 400'
  - D - up to 500'

**A SYSTEM OF URBAN GROWTH**

THESIS  
NICHOLAS NEGROPONTE

SEPTEMBER, 1965