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ING. JOSE ELISEO OCAMPO SAMANO
COORDINADOR DE CURSOS

'eds.

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		SISTEMAS	
28 de Oct.	2 Hs.	Concepto de sistema Tipos de sistemas	Dr. Melchor Rodríguez Caballero
30 "	2 "	Metodología para el análisis y diseño de sistemas	Dr. Melchor Rodríguez Caballero
		Optimización de sistemas	
		EL EDIFICIO COMO SISTEMA	
4 de Nov.	2 "	Sistema interno	Ing. Oscar Alvarez de la Cuadra
6 "	2 "	El medio ambiente urbano	Arq. Octavio Pinedo Navarro
8 "	2 "	El medio ambiente natural	Ing. Jorge Navarro Islas
		El medio ambiente jurídico cultural	Ing. Oscar Alvarez de la Cuadra
		Restricciones tecnológicas	Ing. Sergio Aguilar López
11 "	2 "	Restricciones funcionales	Ing. Sergio Aguilar López
		Restricciones económico-financieras	Ing. Sergio Aguilar López
		Restricciones estéticas	Ing. Sergio Aguilar López
		EL PROCESO VITAL DE UN EDIFICIO	
13 "	2 "	Fases del proceso vital	Dr. Melchor Rodríguez Caballero
15 "	2 "	La dirección de las fases del proceso vital	Dr. Melchor Rodríguez Caballero
18 "	2 "	Fases del proceso de proyecto	Ing. Jorge Navarro Islas
21 y 22 de Nov.	2 Hs. c/día	Síntesis de la forma Modelos de optimización de la forma Modelos de origen-destino	Ing. Sergio Aguilar López

ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

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		CONCEPTOS BASICOS DE ANALISIS ECONOMICO	
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		Flujo de efectivo	" " " "
27 "	2 "	Criterios de evaluación económica	" " " "
		Análisis de costos durante la vida del edificio.	" " " "
		Análisis de ingresos durante la vida del edificio	" " " "
		MODELOS DE OPTIMIZACION ECONOMICA, APLICABLE A EDIFICIOS	
29 "	2 "	Modelo de programación lineal	Ing. Enrique Tercero Barragán
2 de Dic.	2 "	Modelo del valor residual máximo Modelo BOP	Dr. Melchor Rodríguez Caballero Ing. Alejandro García González
4 "	2 "	Modelos del valor máximo de un evaluador económico	Ing. Enrique Tercero Barragán
		MODELOS DE PROGRAMACION Y CONTROL	
6 "	2 "	Ruta crítica	Ing. Alejandro García González
9 "	2 "	Sistemas de presupuestación Sistemas de control presupuestal	Ing. Alejandro García González
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ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

ANALISIS DE SISTEMAS Y DISEÑO EN INGENIERIA ARQUITECTURA, CONSTRUCCION Y PLANEACION

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1. SYSTEMS ANALYSIS AND DESIGN IN ENGINEERING, ARCHITECTURE, CONSTRUCTION AND PLANNING.

Rodolfo V. Aguilar

Prentice Hall, 1973.

CHAPTER 1

Introduction: The Systems Approach

1.1 DECISION MAKING

Many contemporary problems of design and operation in engineering, architecture, construction, and urban and regional planning are of such magnitude and complexity as to require the most systematic and rational approach possible.

Generally, these problems consist of a very large number of interacting variables many of which defy quantification. Therefore, it is necessary first to classify the variables appearing in real life problems into tangible or quantifiable and intangible or unquantifiable. The purpose of the systems approach is to develop methods, mathematical or otherwise, to deal systematically and rationally with the quantifiable parameters of a problem; to increase the set of quantifiable parameters through statistical observation, testing, development of measuring techniques; and to provide a clear understanding of the situation at hand as an aid to the decision maker for subjectively evaluating the intangibles which are present in most real problems.

Physically, a system is composed of a large number of interacting components, each of which may or may not serve a different function, but all of which contribute to a common purpose. Because the components usually involve many areas of knowledge, the only way to implement the systems approach to decision making is through team action, teams involving a spectrum of specialists in seemingly unrelated fields. Systems theory is intended to provide a common basis of understanding between disciplines and, as a result, the systems approach is permeating most fields of knowledge. The physical sciences and engineering have already developed a strong vehicle for interdisciplinary teamwork through the systems approach and, recently, the life sciences as well as the humanities and the social sciences are beginning to apply to their problems the vast methodology that exists in systems analysis and design.

A complex problem can be handled with success when the systems approach is effectively applied. Cost effectiveness, which is a usual gauging device for measuring success, strives to produce a system with the lowest possible cost for a set level of effectiveness or, vice versa, the highest level of effectiveness for a set cost. Combinations of these goals are usual and trade-offs occur when such an approach is taken.

An example of the application of the systems approach to decision making, where no mathematics is needed but where the approach to problem solving recognizes the fundamental behavior of people in developing a realistic policy that can be successfully implemented, is the case of a congested urban area where two local authorities conflict in their plans for city operation and management. One of the authorities, the Planning Commission, attempts to dissuade suburbanites from bringing their personal automobiles into the Central Business District by promoting the use of the Mass Transit System, with the expectation of relieving traffic congestion and reducing the frequency and duration of traffic snarls. On the other hand, the second governmental group, the Port Authority, is charged with the planning, financing, construction, operation, and maintenance of all toll bridges and tunnels leading to the Central Business District. The Port Authority promotes the use of these facilities by offering to the public books of bridge and tunnel toll coupons which can be purchased by the frequent or routine driver at a savings of several dollars per month. A conflict immediately develops because, while one authority tries to discourage the use of personal automobiles in the Central Business District, the other encourages it by offering savings in toll charges. A behavioral solution to this sticky situation was proposed by R. L. Ackoff, Operations Researcher Professor at the University of Pennsylvania: Implement a graduated scale of toll charges as a function of the number of empty seats in a private automobile.

The policy could be developed as follows: Assume a six-passenger car arrives at the toll booth:

1. If all six places are occupied, the car passes free of charge.
2. If one seat is empty—that is, only five passengers are in the car—the charge is, say, $0.25.

3. If two seats are empty, the charge is $0.50.
4. If three seats are unoccupied, the cost now climbs to $1.00, and so on until, say,
5. The driver is the only passenger in the car, in which case the toll is $2.25.

The figures quoted may or may not be realistic but the point is well made. The day after this type of policy was implemented, a marked reduction in the number of cars visiting the Central Business District would most surely be observed. People would probably drive to the outskirts of the downtown area and then form car pools, or they would use the Mass Transit System. A suspected side effect might be an increase in sales of sports cars; with only two seats they would make an inexpensive mode of transportation. This, of course, represents at least a reduction in automobile size and can therefore be considered a desirable side effect. On the other hand, in the interest of fair play, a special tariff could be developed for nonstandard vehicles, and so on. These types of applications are primarily based on common sense, and many such decision rules can be developed without the use of mathematical techniques. However, in some of the most important applications of the systems approach, a great many complex technological questions are raised which require specialized solution techniques. This book concentrates on the development of some of the most important and useful of those techniques.

1.2 THE STRUCTURE OF SYSTEMS ANALYSIS AND DESIGN

Systems analysis is the process of separating or breaking up a whole system into its fundamental elements or component parts. It involves a detailed examination of the system in order to understand its nature and to determine its essential features. Systems design, on the other hand, is the process of selecting the components and of contriving the elements, steps, and procedures for producing a system that will optimally satisfy the stated goals. In the context of this book, systems design is used as a basis for anticipating problems and for solving them at their planning, engineering, architectural, and construction stages. Systems synthesis is akin to design because it is the process of putting together, composing, or combining parts or elements to form a whole system, completely blended to achieve its finest level of performance. Through systems synthesis, often, varied and diverse ideas, forces, or factors are combined into one coherent, consistent structure. In examining complex problems, one must recognize the following classification of elements occurring repeatedly in their solution through the systems approach:

1. *A set of decision and state variables.* The decision variables are those over which the analyst has complete control and which he can manipulate at will. The state variables are those which are dependent on the decision

variables and which, consequently, cannot be directly controlled by the decision maker. Often, the classification of variables into decisions and states is an arbitrary one. However, once they have been so stratified, their behavior follows the stated pattern. This element is basically in the analysis phase of the problem solution and the significance of each variable—that is, how sensitive the problem is to its settings—as well as whether or not the variable is quantifiable must be ascertained in this stage.

2. *An optimization model.* This solution element is necessary for understanding the problem at hand. It involves both analysis and synthesis and consists of the development of a conceptual model which is sufficiently analogous to the real problem but which, on the other hand, is simple enough to be amenable to quantitative analysis.

3. *A measure of effectiveness.* Called the objective function, this measure is formulated as a means for evaluating the degree of success or failure attained in fulfilling the problem goals. It relates various decision and state variables for the expressed purpose of ranking the outcome of the different decision sets.

4. *Generation of alternatives and optimal solution.* After the problem has been formulated quantitatively, the sets of decisions arrived at following a rational, systematic plan are evaluated by means of the objective function, and the one producing the most desirable results is selected. The different sets of decisions are the alternative plans of action and the selection of the most desirable outcome constitutes the optimization phase of the problem solution; the decision policy producing the best results is the optimal policy. Frequently, a system cannot be completely optimized. Near optimal results are often extremely valuable, especially when the objective function is not too sensitive to changes in the values of the decision and state variables near the optimum. This phase of problem solution is primarily a design phase.

5. *Policy implementation.* This step involves the carrying out of the optimal policy into the real physical situation. It constitutes, in fact, the realization of the objective and the only reason for having gone through the previous four steps. Usually, because of additional knowledge gained or because conditions change, the analyst finds it necessary to recycle the process by returning to one of the previous steps. This recycling is required in adaptive or learning processes where newly acquired data permit the system to refine itself and to adapt to a changing environment.

3 CLASSIFICATION OF DECISION SYSTEMS

engineering, architecture, construction, and planning, decision systems be classified according to size and according to predictability of behavior follows.

I. According to size:
   1. *Simple systems* are those which involve only a relatively small number of quantifiable decision and state variables.
   2. *Complex systems* involve a large number of decision and state variables. However, the variables are, by and large, of the quantifiable type.
   3. *Exceedingly complex systems.* These consist of a large number of decision and state variables, most of which are of a non-quantifiable nature.

II. According to behavioral predictability:
   1. *Deterministic systems* are those for which every input produces a predictable response. Furthermore, the system's responses to identical inputs are themselves identical.
   2. *Stochastic systems* involve randomly determined sequences of observations, each of which is considered as a sample from a probability distribution. Stochastic variation implies system randomness in passing from one state to an adjacent state. A stochastic system's response to a specified input is not reproducible at will—that is, one cannot expect exactly the same behavior when the system is subjected to identical inputs.

Table 1-1 gives examples of different types of systems classified according to the rules previously formulated. Note that the set of exceedingly complex deterministic systems is assumed to be empty; there are no physical systems which can be classified in this category because all exceedingly complex systems possess a multitude of random parameters.

TABLE 1-1. Examples of Different Types of Systems.

Systems	*Deterministic*	*Stochastic*
Simple	Beam Deflection	Toss of Coin
Complex	Planetary System	Inventory System
Exceedingly Complex	Empty	The City

1.4 FIELDS OF SPECIALTY IN SYSTEMS ANALYSIS AND DESIGN

The systems approach to complex problem solving encompasses a broad field of work and, as such, takes on different meanings for the people involved in it, depending upon the area or areas of their specific interest and experience. Five fields of specialty can be recognized although, in most instances, they tend to overlap and run into each other as the nature of the work in systems analysis and design demands an interdisciplinary, team approach.

1. *Deterministic and stochastic optimization.* In a few words, optimization deals with the methods and procedures required to obtain the most benefit at the least possible cost. This book concentrates on the mathematical and heuristic optimization techniques applicable to deterministic and stochastic systems. In section 1.5 the general concept of optimization will be discussed further.

2. *Control theory.* Certain physical processes change so rapidly that to maintain an optimal level of performance it is necessary to adjust continuously the setting of the decision and state variables. Control theory deals with the methods and procedures needed to allow a system to adapt itself to changing conditions without upsetting it dynamically, and to keep its performance characteristics at an optimum.

Chemical and electrical engineers, for example, utilize extensively the techniques of control theory because many of the problems encountered in their fields are of the process type where continuous monitoring is essential to efficiency of operation.

3. *Information systems.* This systems area concerns itself with the structure, analysis, organization, storage, searching, and retrieval of information. The entire subject has received an increasing amount of attention in recent years, not only because simpler information handling systems are urgently needed, but also because planning and design, in whatever field, must rely on an extensive data base of high quality to be a useful tool in solving the complex problems of today and of the future. The information systems fields include elements of linguistics, mathematics, and computer programming.

4. *Numerical analysis and methods.* The computer, with its enormous speed and ability to manipulate large blocks of information, is the most useful tool available to the systems analyst and designer. Computers are of either of two basic types: (1) digital computers which are basically extremely rapid, electronic adding machines, or (2) analog computers which permit the solution of a complex problem by establishing a mathematical analogy between the problem functions and variables and a flow of electric current or a fluid. Certain problems require the coupling of digital and analog computers; this combination has come to be known as a hybrid computer. In any case, the analyst must be capable of transforming the physical problem into a mathematical one and of directing its programming for computer solution. The inclusion of the field of numerical analysis in the systems area grows out of this need. This book will present to the reader a large number of examples showing how to implement the process of going from the physical problem to its mathematical analog. This process, called modeling in the language of systems analysis, is perhaps the most difficult as well as the most important phase of problem solving.

5. *Digital, analog, and hybrid computer simulation.* This area involves the manipulation and observation of a synthetic model representing a real physical system which, for technical, economic, or other reasons, may not be suitable for experimentation. The synthetic model, usually mathematical in nature, ideally represents the essential characteristics of the physical system. In contrast with analytical models which are solved exactly or approximately, simulation models are run. The simulator observes the behavior of the model, gathers pertinent data, and draws appropriate conclusions. Digital, analog, and hybrid computers are normally used to run simulation models.

1.5 OPTIMIZATION METHODS AND APPLICATIONS

Leibniz coined the word "optimum" in 1710 as a result of his speculations about the nature of the universe and of its creation. He wrote:

> There is an infinitude of possible worlds, among which God must needs have chosen the best, since He does nothing without acting in accordance with supreme wisdom. Now this supreme wisdom, united to a goodness that is no less infinite, cannot but have chosen the best. . . . As in mathematics, when there is no maximum or minimum, everything is done equally or . . . nothing at all is done: so it may be said . . . that if there were not the best (optimum) among all possible worlds, God would not have produced any.

Those adhering to this philosophy of Leibniz came to be known as optimists when in reality they turned out to be fatalists by reasoning that if God in all of His wisdom and goodness could not make the world any better, what could a powerless human being do to change it? Optimization, with many other branches of human knowledge, had a strictly philosophical beginning. Today, however, although its philosophical implications continue to be of interest, its emphasis is on the solution of complex problems from the real world.

From the standpoint of methodology, optimization techniques can be divided into indirect and direct. Indirect techniques permit the selection of an optimal point without requiring an examination of nonoptimal points. These methods are very effective when they can be applied. This book concentrates primarily on their study. Direct methods start at an arbitrary point and proceed stepwise toward the peak by successive improvements. Chapter 10 is dedicated to the study of direct methods.

From the standpoint of the type of systems to which they are applied, optimization procedures yield various kinds of decision-making strategies:

1. *Decision making under certainty* applies to deterministic systems where the probability of occurrence of each event is one.

2. *Decision making under risk* applies to stochastic systems where the probability of occurrence of each event is known but lies somewhere between zero (nonoccurrence) and one (occurrence).
3. *Decision making under uncertainty* applies to stochastic systems with unknown probability distributions.
4. *Adaptive decision making* results when the analyst is able to conduct a sequence of experiments in order to acquire knowledge about the probability distributions involved. This category is intermediate between risk and uncertainty and in many respects can be classified as a simulation type. Chapters 12 and 13 discuss stochastic systems in some detail.
5. Finally, *decisions can be formulated individually or by groups.* In group decision making, the process may be carried out under collaboration or under competition. Chapter 14 introduces the reader to decision making under competition with risk; the subject is called "Game Theory."

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CHAPTER 2

Economic Considerations

2.1 INTRODUCTION

Projects of any kind become a reality only if they are technologically and financially feasible. Technological feasibility lies in the realm of professional know-how and ability. Financial feasibility depends upon the project's ability to show a profit to the investor through time.

This chapter will concentrate on the development of procedures, not only for assessing correctly the feasibility or infeasibility of a particular project, but also for comparing alternative investment opportunities. The methods that will be developed in this chapter will show what data are needed to translate estimates into business decisions.

An overwhelming majority of physical projects have an "investment for return" orientation and, for the investor, the most important question to be answered is: Will the venture pay? Training, experience, and a great deal of imagination are required to find the most economical or the most profitable solution to any given problem. In general, the solution must be formulated under sets of constraints; typical are a fixed budget, environmental needs, aesthetic requirements, zoning regulations, safety standards, socioeconomic trends, technological limitations, and so on, which make arriving at the optimal solution a very difficult task. The obvious complexity of the problem tempts one to formulate intuitive decisions. Unfortunately, these types of decisions are unreliable and dangerous and must be discarded whenever possible. Although complete optimization of a project is frequently impractical, near optimal solutions involving imperfect alternatives are often good enough to provide extremely satisfactory answers. Economic studies serve to identify clearly all of the alternative methods of solving a particular problem and of quantifying those alternatives by reducing them to a monetary basis.

2.2 THE CONCEPT OF INTEREST

Because of the existence of interest, money is worth more today than sometime in the future. Interest is the direct result of two behavioral phenomena:

1. Man has a finite life span and for this reason people are not willing to postpone enjoyment of material goods because of the inherent uncertainties of life.
2. There is a fundamental trade-off rule that appears to apply to most people: The more one has of something, the more one is willing to trade it for something else one does not have enough of. The second rule gives rise to the so-called indifference curves frequently used by economists.

If one asked somebody whether he would rather have, say, $1,000 today or $1,000 one year from today, any sane person would most assuredly respond: "Today!" Suppose that one upped the reward $100 for a delay of one year and that the question were rephrased: "$1,000 today or $1,100 one year from today?" The individual might still prefer $1,000 today. Continuing in this fashion, one would state at some point: "How about $1,000 today or $1,400 a year from today?" If, after some thought, the person responds, "I prefer to wait a year to get the $1,400," his so-called attractive annual rate of return would be 40% under this set of circumstances. That is, he is willing to wait a whole year in order to realize a 40% increase in financial return.

On this basis, *interest* can be defined as the money that must be paid for the use of borrowed money. That is, the person in the example above would be willing to lend $1,000 to a borrower in the expectation of a 40% return. The borrower would be paying 40% interest on his loan; a scandalously high rate but, nevertheless, a rate paid by many unsuspecting customers. The "truth in lending" law now requires that the true rate of interest be clearly and unequivocally stated by lenders. A review of finance company advertisements would reveal that annual interest rates in the 25% to 45% bracket are not uncommon.

A more operational definition of interest is the return derived from capital productively invested. *Interest rate* is the ratio between the amount of interest chargeable or payable at the end of a specific time period, usually one year, and the money borrowed at the beginning of the period. In general, the interest rate is "per annum" (per year), unless stated otherwise. For example, a 6% interest payable annually represents a 0.06 interest rate per year. This is equivalent to 0.015 payable quarterly, or 0.005 payable monthly. There is a slight difference between the payment of interest annually and its payment at more frequent intervals. This difference will be discussed in detail in later sections.

If the interest payable each year is computed on the total amount owed at the end of the previous year—the total amount that includes the original principal sum borrowed plus the interest that was not paid when due and that, consequently, has accumulated—the interest is said to be *compound*. *Simple* interest is that payable as a charge on the original principal sum only. This type of interest will not be discussed further because it is not generally encountered in practice and its computation is direct.

To illustrate the difference between simple and compound interest, consider the repayment of $10,000 at the end of 5 years for an 8% loan under

TABLE 2.1. Simple and Compound Interest.

8% SIMPLE INTEREST

Year	*Amount Owed at Beginning of Year*	*Interest Owed at End of Year*	*Amount Owed at End of Year*
1	$10,000	$800	$10,800
2	$10,800	$800	$11,600
3	$11,600	$800	$12,400
4	$12,400	$800	$13,200
5	$13,200	$800	$14,000

8% COMPOUND INTEREST

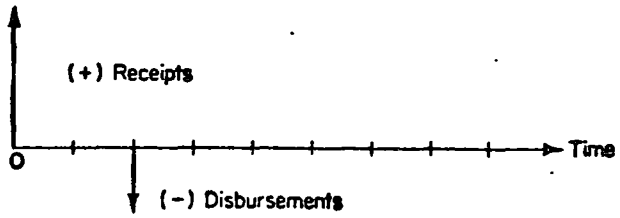
Year	*Amount Owed at Beginning of Year*	*Interest Owed at End of Year*	*Amount Owed at End of Year*
1	$10,000	$800	$10,800
2	$10,800	$864	$11,664
3	$11,664	$933	$12,597
4	$12,597	$1,008	$13,605
5	$13,605	$1,088	$14,693

each plan, as given in Table 2.1. Under the 8% simple interest plan, the interest owed at the end of each year is computed on the $10,000 principal only and is a constant $800. For the 8% compound interest case, the interest is computed on the total amount (principal plus interest) owed at the end of the previous year. The amount increases from $800 at the end of the first year to $1,088 at the end of the fifth. Rounding off to the nearest dollar, the difference in cost to the borrower is $693 at the end of 5 years. This quantity is the amount the borrower pays for the use of the accumulated interest money throughout the duration of the plan.

2.3 CASH FLOW DIAGRAMS

Because of interest, money has different value through time. This results in the concept that money has "time-value." Since most investment situations involve disbursements and receipts of money through time, it is convenient to develop a semigraphical method of analysis. Cash flow diagrams provide a rational, simple way of showing how money flows through time. Figure 2.1 depicts a typical cash flow diagram. Plotted along a time axis are both receipts (positive cash flow) and disbursements (negative cash flow). It is irrelevant on which side of the time axis they are plotted, however; in this book receipts will be plotted above the time axis and disbursements below it.

FIGURE 2.1. Cash Flow Diagram.



It must be pointed out that the terms receipts and disbursements are relative as to who is receiving and paying out the money. The borrower's receipt is the lender's disbursement and vice-versa.

2.4 BASIC ASSUMPTION IN INTEREST COMPUTATIONS

For the purpose of alternative comparisons, it is well to assume that cash disbursements and receipts occur only at the end of each time period (normally one year). More frequent cash movement introduces a slight error in the computations which is of little significance in performing the types of analyses of interest to planners. For example, although repayment of principal and interest (debt service) on improved real estate property is normally done at the end of each month, with a very small error and with much simplification in the computations, the total for twelve months can be assumed to be repaid at the end of each year instead. Normally, this practice provides more than sufficient accuracy.

2.5 DECIDING BETWEEN ALTERNATIVES

It is always differences in cost or profit which are significant in selecting between alternatives. The concept of cost, or profit, must be related to specific alternatives in order to serve as a useful guide in business decision making. It must be pointed out that, although many data are irreducible to money terms, any final intelligent decision must give proper weight to the quantifiable factors as well as to the unquantifiable ones and, of course, the more one is able to quantify the elements of a problem the more reliable the decisions become. After all, the objective of an economy study is to establish a rational base for selecting between alternatives, and any information which tends to clarify the choices is of paramount importance to the goal of such a study.

2.6 THE QUESTION OF INCOME TAXES

The study of taxation is a field all to itself and no attempt will be made here to become involved in such a complex subject. Before-tax computations will be the general method used for the purposes of this book. However, the analyst must be totally aware of the tax implications of each alternative under consideration; he should seek expert advice on these and other matters which could be of vital importance to his projects.

2.7 METHODS OF ANALYSIS

Four methods of analysis of cash flow situations will be discussed in detail:

1. Present worth computations.
2. Equivalent uniform annual cash flow.
3. True rate of return computations.
4. Benefit-cost ratio.

All of these methods serve to reduce money figures through time to a common base for comparison purposes. However, before they can be studied, the reader must be totally familiar with the basic interest formulas and their use in specific situations.

2.8 INTEREST SYMBOLS AND FORMULAS

2.8.1 Symbols

Five parameters appear in interest formulas and computations. They are:

1. $i \longrightarrow$ the *interest* rate per period.
2. $n \longrightarrow$ the *number* of interest periods.
3. $P \longrightarrow$ a *present* sum of money.
4. $F \longrightarrow$ a *future* sum of money.
5. $A \longrightarrow$ an *annual* payment (or a payment per period).

These symbols are mnemonic—that is, they serve as memory aids—and for this reason have been adopted for interest computations.

As will be seen later, in interest problems *four* of the *five* parameters i, n, P, F, and A are always present and *three* of the *four* must be known (given as data); the object of the problem is to compute the missing fourth parameter.

An important comment must be made here; interest tables are conventionally based upon payments made at the *end* of each payment period and *not* at the beginning or anywhere in between. This characteristic of the formulas will be clearly understood when they are derived.

2.8.2 Formulas

There are six basic interest formulas belonging to two separate categories:

I. Single Payment Formulas	1. Compound Amount Factor. 2. Present Worth Factor.
II. Uniform Series of Payments Formulas	3. Sinking Fund Factor. 4. Compound Amount Factor. 5. Capital Recovery Factor. 6. Present Worth Factor.

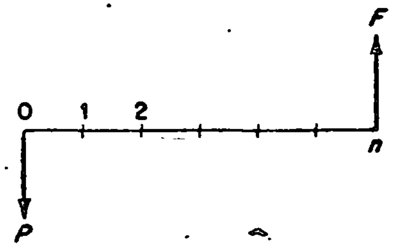
2.8.2.1 Single Payment Formulas (I)

As the name implies, a single disbursement and receipt, through time, is involved in each of these formulas.

The cash flow diagram for the two formulas is given in Figure 2.2.

1. *Compound amount factor.* What future sum of money F can be obtained from investing P dollars today (at the end of year zero), at $i\%$ annual interest, for n years? Note that the four elements involved are: P, i, n, and F. Three are known: P, i, and n. The unknown F is computed thus,

FIGURE 2.2. Cash Flow Diagram for Single Payment Formulas.



$$F = (F \longrightarrow P, i\%, n)P. \tag{2.1}$$

Equation (2.1) is meant to be read: F equals the compound amount factor $(F \longrightarrow P, i\%, n)$, multiplied by P. Note that the symbol for the compound amount factor is functional in that it shows F is to be computed given that $\longrightarrow P, i\%$, and n are known. Numerical values of the compound amount factor are supplied in the tables of Appendix A. These values are tabulated under column one, headed $(F \longrightarrow P)$ for interests $i\%$ varying from 1% to 50%, and for number of interest periods, n, varying from 1 to 50 in most cases. The algebraic formula for the compound amount factor is computed as follows: If P dollars are invested at interest i, the interest for the first year is iP and the total amount at the end of the first year is

$$P + iP = P(1 + i). \tag{2.2}$$

The second year the interest on this amount $P(1 + i)$ is $iP(1 + i)$ and the total amount accumulated at the end of the second year is

$$\begin{aligned} P(1 + i) + iP(1 + i) &= P(1 + i)(1 + i) \\ &= P(1 + i)^2. \end{aligned} \tag{2.3}$$

Similarly, at the end of the third year the amount is $P(1 + i)^3$; at the end of n years it is $P(1 + i)^n$. Consequently,

$$(F \longrightarrow P, i\%, n) = (1 + i)^n. \tag{2.4}$$

Example 1:

Mr. Jones deposits \$3,000 in a savings account which pays 4% annual interest. How much money would he have accumulated at the end of 5 years?

Solution:

$$P = \$3{,}000;\ i\% = 4\%;\ n = 5;\ F = ?$$

$$F = (F \longrightarrow P, 4\%, 5)3{,}000.$$

From Table A-9,

$$(F \longrightarrow P, 4\%, 5) = 1.2167.$$

Therefore,

$$F = 1.2167 \times 3{,}000 = \$3{,}650.$$

NOTE: For most computations, slide rule approximation provides sufficient accuracy in comparing alternative planning investments.

2. *Present worth factor.* The present worth factor is the reciprocal of the compound amount factor. How much money, P, should be invested today (at the end of year zero), at $i\%$ annual interest, for n years to accumulate a future sum of money F?

The functional relationship for present worth is

$$P = (P \longrightarrow F, i\%, n)F. \tag{2.5}$$

The algebraic equivalence of the functional formula for present worth is easily computed from the compound amount relationship.

From equations (2.1) and (2.4),

$$F = (1 + i)^n P. \tag{2.6}$$

Therefore,

$$P = \left[\frac{1}{(1 + i)^n}\right]F. \tag{2.7}$$

Numerical values for single payment present worth factors are given in column two of each table in Appendix A.

Example 2:

Mr. Smith determines that he will need $4,000, 10 years from today, to help defray the cost of his eldest son's college education. How much money should he deposit now in a savings account paying 5% annual interest to accumulate the needed funds in 10 years?

Solution:

$$F = \$4{,}000;\ i\% = 5\%;\ n = 10;\ P = ?$$
$$P = (P \longrightarrow F, 5\%, 10)4\,000.$$

From Table A-11,

$$(P \longrightarrow F, 5\%, 10) = 0.6139.$$

Therefore,

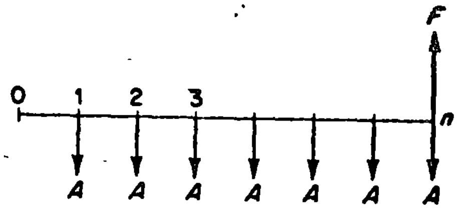
$$P = 0.6139 \times 4{,}000 = \$2{,}456.$$

2.8.2.2 Uniform Series of Payments Formulas (II)

These formulas involve series of equal payments.

3. *Sinking fund factor.* How much money A should be invested at the end of each year, at $i\%$ for n years, to accumulate a stipulated future sum of money F? The cash flow diagram for this situation is given in Figure 2.3.

FIGURE 2.3. Cash Flow for a Sinking Fund.



The functional relationship is

$$A = (A \longrightarrow F, i\%, n)F. \tag{2.8}$$

The numerical values of the sinking fund factor $(A \longrightarrow F, i\%, n)$ are given in column three of the tables in Appendix A. The algebraic formula for the sinking fund factor is obtained as follows:

If A is invested at the end of each year for n years, the total amount F accumulated at the end of n years will obviously equal the sum of the compound amounts of the individual investments. The amount A invested at the end of the first year will earn interest for $n - 1$ years; therefore, its compound amount will be $A(1 + i)^{n-1}$. The second year's investment will amount to $A(1 + 1)^{n-2}$ at the end of the $n - 2$ years left. The third year's investment will be $A(1 + i)^{n-3}$ and so on, until the last year (the end of year n) in which the investment earns no interest and, consequently, amounts to only A. The total amount F is, therefore,

$$F = A(1 + i)^{n-1} + A(1 + i)^{n-2} + A(1 + i)^{n-3} + \cdots + A. \tag{2.9}$$

This can be rewritten,

$$F = A[1 + (1 + i) + (1 + i)^2 + \cdots + (1 + i)^{n-2} + (1 + i)^{n-1}]. \tag{2.10}$$

Multiplying both sides by $(1 + i)$, obtain

$$F(1 + i) = A[(1 + i) + (1 + i)^2 + (1 + i)^3 + \cdots + (1 + i)^{n-1} + (1 + i)^n]. \tag{2.11}$$

Subtract equation (2.10) from equation (2.11), thus

$$iF = A[(1 + i)^n - 1].$$

Consequently,

$$A = \left[\frac{i}{(1 + i)^n - 1}\right]F. \tag{2.12}$$

Therefore,

$$(A \longrightarrow F, i\%, n) = \frac{i}{(1 + i)^n - 1}. \tag{2.13}$$

Example 3:

Suppose that Mr. Smith in Example 2 cannot afford to deposit $2,456 today at 5% to accumulate $4,000 at the end of 10 years. Instead, he wishes to determine how much money he should deposit at the end of each year for 10 years to generate the same $4,000 savings.

Solution:

$$F = \$4{,}000;\ i\% = 5\%,\ n = 10;\ A = ?$$

$$A = (A \longrightarrow F,\ 5\%,\ 10)4{,}000.$$

From Table A–11,

$$(A \longrightarrow F,\ 5\%,\ 10) = 0.07950.$$

Therefore,

$$A = 0.07950 \times 4{,}000 = \$318 \text{ per year.}$$

4. *Compound amount factor.* If A dollars are invested at $i\%$ for n years, how much money F will be accumulated during that period?

$$F = (F \longrightarrow A,\ i\%,\ n)A. \tag{2.14}$$

The algebraic value of the compound amount factor for a uniform series of payments is obtained directly from equation (2.12).

Since

$$A = \left[\frac{i}{(1+i)^n - 1}\right]F,$$

then

$$F = \left[\frac{(1+i)^n - 1}{i}\right]A,$$

and, therefore,

$$(F \longrightarrow A,\ i\%,\ n) = \frac{(1+i)^n - 1}{i}. \tag{2.15}$$

The compound amount factor for a uniform series of payments is the reciprocal of the sinking fund factor. Its numerical values are tabulated in column five of the tables in Appendix A.

Example 4:

What sum of money will be generated by $1,000 invested at the end of each year for 8 years in an investment yielding 6% return?

Solution:

$$A = \$1{,}000;\ i\% = 6\%;\ n = 8;\ F = ?$$

$$F = (F \longrightarrow A,\ 6\%,\ 8)1{,}000.$$

From Table A–8,

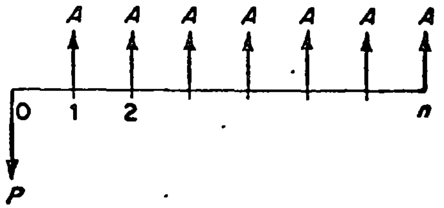
$$(F \longrightarrow A,\ 6\%,\ 8) = 9.897.$$

Therefore,

$$F = 9.897 \times 1{,}000 = \$9.897.$$

5. *Capital recovery factor.* If P dollars are invested today at $i\%$, how many dollars, A, can be secured at the end of each year for n years such that the initial investment, P, is depleted? The cash flow diagram for this plan is given in Figure 2.4.

FIGURE 2.4. Cash Flow for Capital Recovery.



Note that capital recovery, as its name implies, refers to the number of future equal end-of-the-year payments, A, needed to recover an initial investment, P, in n years at $i\%$. The functional relationship is,

$$A = (A \longrightarrow P,\ i\%,\ n)P.$$

The algebraic formula for the capital recovery factor $(A \longrightarrow P,\ i\%,\ n)$ can be computed from the sinking fund relationship, equation (2.8), as follows:

$$A = (A \longrightarrow F,\ i\%,\ n)F. \tag{2.16}$$

To reduce F to P, use the compound amount relation, equation (2.1), and substitute it in the expression given above to obtain

$$A = (A \longrightarrow F,\ i\%,\ n)(F \longrightarrow P,\ i\%,\ n)P. \tag{2.17}$$

Consequently, from equations (2.16) and (2.17),

$$(A \longrightarrow P,\ i\%,\ n) = (A \longrightarrow F,\ i\%,\ n)(F \longrightarrow P,\ i\%,\ n). \tag{2.18}$$

The algebraic equivalence is derived from equations (2.4) and (2.13)

$$(A \longrightarrow P, i\%, n) = \left[\frac{i}{(1+1)^n - 1}\right](1+i)^n,$$

or

$$(A \longrightarrow P, i\%, n) = \frac{i(1+i)^n}{(1+i)^n - 1}. \tag{2.19}$$

This equation can also be expressed as

$$(A \longrightarrow P, i\%, n) = \frac{i + i(1+i)^n - i}{(1+i)^n - 1},$$

$$= \frac{i[1 + (1+i)^n - 1]}{(1+i)^n - 1},$$

$$(A \longrightarrow P, i\%, n) = \frac{i}{(1+i)^n - 1} + i. \tag{2.20}$$

Expression (2.20) shows that the capital recovery factor equals the sinking fund factor, equation (2.13) plus the interest rate. Thus,

$$(A \longrightarrow P, i\%, n) = (A \longrightarrow F, i\%, n) + i. \tag{2.21}$$

Numerical values of the capital recovery factor are given in column four of the tables in Appendix A.

Example 5:

What should be the annual return from an investment of \$10,000 at 4.5% for 15 years?

Solution:

$$P = \$10{,}000;\ i\% = 4.5\%;\ n = 15;\ A = ?$$
$$A = (A \longrightarrow P, 4.5\%, 15)10{,}000.$$

From Table A-10,

$$(A \longrightarrow P, 4.5\%, 15) = 0.09311.$$

Therefore,

$$A = 0.09311 \times 10{,}000 = \$931 \text{ per year.}$$

6. *Present worth factor.* How much money P should be invested today at $i\%$ to recover A dollars at the end of each year for n years?

$$P = (P \longrightarrow A, i\%, n)A. \tag{2.22}$$

The present worth factor $(P \rightarrow A, i\%, n)$ is the reciprocal of the capital recovery factor. Therefore, its algebraic formula is

$$(P \longrightarrow A, i\%, n) = \frac{(1+i)^n - 1}{i(1+i)^n}. \tag{2.23}$$

Equation (2.23) is the reciprocal of equation (2.19). Numerical values of $(P \rightarrow A, i\%, n)$ are given in column six of the tables in Appendix A.

Example 6:

What amount P should be invested at 8% to generate a return of \$1,000 at the end of each year for the next 12 years?

Solution:

$$A = \$1{,}000;\ i\% = 8\%;\ n = 12;\ P = ?$$
$$P = (P \longrightarrow A, 8\%, 12)1{,}000.$$

From Table A-15,

$$(P \longrightarrow A, 8\%, 12) = 7.536.$$

Therefore,

$$P = 7.536 \times 1{,}000 = \$7{,}536.$$

2.8.3 Summary of Interest Factors

1. Single Payment Compound Amount Factor

$$(F \longrightarrow P, i\%, n) = (1+i)^n. \tag{2.24}$$

2. Single Payment Present Worth Factor

$$(P \longrightarrow F, i\%, n) = \frac{1}{(1+i)^n}. \tag{2.25}$$

3. Series of Payments Sinking Fund Factor

$$(A \longrightarrow F, i\%, n) = \frac{i}{(1+i)^n - 1}. \tag{2.26}$$

4. Series of Payments Compound Amount Factor

$$(F \longrightarrow A, i\%, n) = \frac{(1+i)^n - 1}{i}. \tag{2.27}$$

5. Series of Payments Capital Recovery Factor

$$(A \longrightarrow P, i\%, n) = \frac{i(1+i)^n}{(1+i)^n - 1} = \frac{i}{(1+i)^n - 1} + i. \tag{2.28}$$

6. Series of Payments Present Worth Factor

$$(P \longrightarrow A, i\%, n) = \frac{(1+i)^n - 1}{i(1+i)^n}. \tag{2.29}$$

2.8.4 Relationship Between Interest Factors

1. $(F \longrightarrow P, i\%, n) = \dfrac{1}{(P \longrightarrow F, i\%, n)}.$ (2.30)
2. $(A \longrightarrow F, i\%, n) = \dfrac{1}{(F \longrightarrow A, i\%, n)}.$ (2.31)
3. $(A \longrightarrow P, i\%, n) = \dfrac{1}{(P \longrightarrow A, i\%, n)}.$ (2.32)
4. $(A \longrightarrow P, i\%, n) = (A \longrightarrow F, i\%, n) + i.$ (2.33)

2.8.5 Other Interest Formulas

Although other interest formulas can be just as easily derived, they are not as important as the six basic formulas already given. Formulas for gradient series, continuous compounding, and so on, as well as numerical tables for many of them, can be found in the references.

2.9 NOMINAL AND EFFECTIVE RATES OF INTEREST

Suppose that interest is compounded more frequently than once per year. Many banks, for instance, compound interest quarterly or even more frequently on their savings accounts. The more frequent the compounding, the higher the yield of a specified interest rate.

Let interest be compounded m times per year at a rate i/m per compounding period.

The nominal rate per year is

$$m\left(\frac{i}{m}\right) = i. \tag{2.34}$$

The effective rate per year is

$$\left(1 + \frac{i}{m}\right)^m - 1. \tag{2.35}$$

Formula (2.35) simply states that the effective interest per unit (dollar) is the compound amount at the end of m periods per year, minus the initial investment of one unit (dollar).

For example, a nominal rate $i = 0.12$ (12% annual interest) has the following effective rates:

1. Compounded annually,

$$\text{Effective Rate} = 0.12$$

2. Compounded semiannually,

$$\text{Effective Rate} = \left(1 + \frac{0.12}{2}\right)^2 - 1 = 0.1236$$

3. Compounded monthly,

$$\text{Effective Rate} = \left(1 + \frac{0.12}{12}\right)^{12} - 1 = 0.1268$$

2.10 PROCEDURE FOR FINDING AN UNKNOWN RATE OF INTEREST

Because interest formulas are nonlinear, the most efficient method for finding an unknown rate of interest is by trial and error, using the tables of Appendix A and linearly interpolating between values. The interpolation produces an error which is negligible for most applications.

Example 7:

A company invested $10,000 in a piece of property 15 years ago. Today the company sold the property for $22,000. What is the return on the $10,000 investment?

Solution:

$$P = \$10{,}000;\ F = \$22{,}000;\ n = 15;\ i\% = ?$$

By interpolation:

$$F = (F \longrightarrow P, i\%, 15)P,$$

or,

$$22{,}000 = (F \longrightarrow P, i\%, 15)10{,}000.$$

Consequently,

$$(F \longrightarrow P, i\%, 15) = \frac{22{,}000}{10{,}000} = 2.2000.$$

Looking through the tables one finds:

$$(F \longrightarrow P, 5\%, 15) = 2.0789, \text{ from Table A.11.}$$
$$(F \longrightarrow P, 5.5\%, 15) \doteq 2.2325, \text{ from Table A.12.}$$

Consequently, by interpolation,

$$i\% = 5\% + \left(\frac{2.2000 - 2.0789}{2.2325 - 2.0789}\right)0.5\%$$
$$i\% = 5\% + 0.395\% = 5.39\% \text{ return.}$$

Exact Solution:

$$(F \longrightarrow P, i\%, 15) = (1 + i)^{15} = 2.2000.$$

Therefore,

$$1 + i = \sqrt[15]{2.2},$$
$$i = \sqrt[15]{2.2} - 1.$$

Using logarithms, find

$$i\% = 5.397\%.$$

The error is, in fact, negligible.

2.11 ADDITIONAL EXAMPLES OF APPLICATION

It is well to repeat here three important observations made previously:

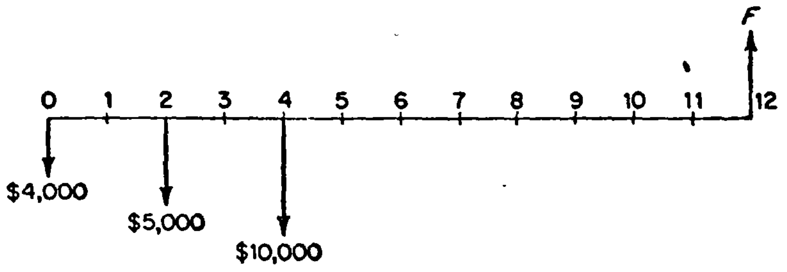
1. In each problem *four* of the five elements P, F, A, i, and n appear. Three of the four must be known (must be given as data).
2. Interest formulas and their associated tables are based upon payments made at the *end* of each payment period.
3. Slide rule accuracy is sufficient here for most applications of interest.

Example 8:

If $4,000 is invested now, $5,000 two years hence, and $10,000 four years hence, all at 5% interest, what will be the total accumulated amount 12 years from today?

Solution:

The cash flow diagram for this problem is



To compute F, note that the compound amount factor must be applied to the different deposits for different numbers of years. Thus,

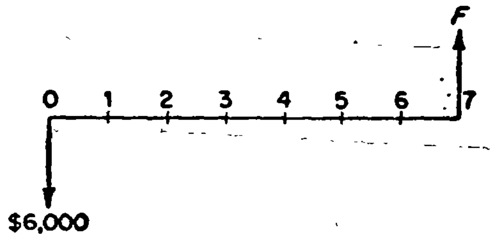
$$F = (F \longrightarrow P, 5\%, 12)4{,}000 + (F \longrightarrow P, 5\%, 10)5{,}000$$
$$+ (F \longrightarrow P, 5\%, 8)10{,}000.$$

From Table A-11.

$$F = 1.7959 \times 4{,}000 + 1.6289 \times 5{,}000 + 1.4775 \times 10{,}000,$$
$$F = \$30{,}100.$$

Example 9:

What is the compound amount of $6,000 for 7 years with interest at 8% compounded quarterly?



Solution:

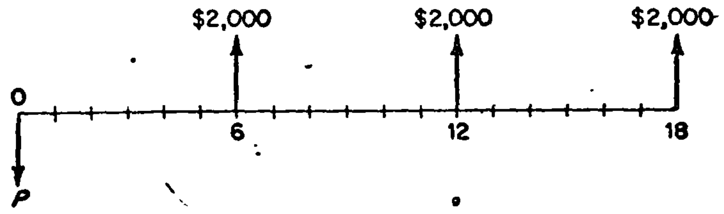
Because the interest is compounded quarterly (four times per year), the effective interest for a nominal 8% per year is equivalent to 2% per period (quarter) for 28 periods (7 years). Therefore,

$$P = \$6{,}000;\ i\% = 2\%;\ n = 28;\ F = ?$$
$$F = (F \longrightarrow P, 2\%, 28)6{,}000 = 1.7410 \times 6{,}000 = \$10{,}446.$$

Example 10:

Compute the present worth of $2,000 at the end of each 6-year period for the next 18 years if interest is at 6%.

Solution:

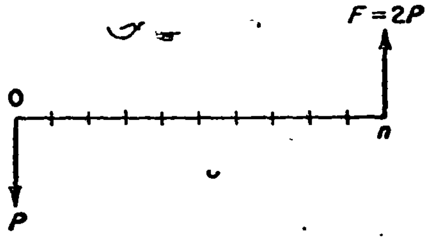


$$P = 2{,}000[(P \longrightarrow F, 6\%, 6) + (P \longrightarrow F, 6\%, 12) + (P \longrightarrow F, 6\%, 18)]$$
$$= 2{,}000[0.7050 + 0.4970 + 0.3503] = \$3{,}100.$$

Example 11:

How long will it take for money to double itself with interest at 6%?

Solution:



From the 6% interest table, find that for $n = 11$,

$$(F \longrightarrow P, 6\%, 11) = 1.8983.$$

For $n = 12$,

$$(F \longrightarrow P, 6\%, 12) = 2.0122.$$

Therefore, it takes, approximately,

$$n \simeq 11 + \left(\frac{2.0000 - 1.8983}{2.0122 - 1.8983}\right)1 = 11.89 \text{ years}$$

for money to double itself at 6% interest.

Example 12:

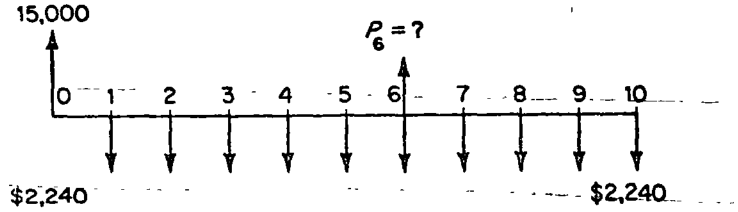
How much must be paid each year during 10 years to repay a loan of \$15,000 if interest is 8%?

Solution:

$$P = \$15{,}000;\ i\% = 8\%;\ n = 10;\ A = ?$$
$$A = (A \longrightarrow P, 8\%, 10)\ 15{,}000$$
$$= 0.14903 \times 15{,}000 = \$2{,}240 \text{ per year.}$$

Example 13:

How much would still be owed after the sixth payment has been made on the loan of Example 12?



Solution:

Immediately after the sixth payment has been made, there are still four more payments to make. The question could be rephrased: What is the present worth (at the end of year 6), P_6, of four annual payments of \$2,240 at 8% interest?

$$P_6 = (P \longrightarrow A, 8\%, 4)2{,}240$$
$$= 3.312 \times 2240 = \$7{,}400.$$

This shows that during the first six years only \$7,600 was amortized. The rest of the money went to pay the interest.

Example 14:

An investment of \$100,000 produces a return of \$14,000 per year for 16 years. What is this investment's approximate rate of return?

Solution:

$$P = \$100{,}000;\ A = \$14{,}000;\ n = 16;\ i\% = ?$$
$$100{,}000 = (P \longrightarrow A, i\%, 16)14{,}000.$$

Therefore,

$$(P \longrightarrow A, i\%, 16) = \frac{100{,}000}{14{,}000} = 7.14.$$

Scan the tables in Appendix A for a series of payments present worth factor of 7.14 in 16 years.

$$\text{For } i = 10\%\ (P \longrightarrow A, 10\%, 16) = 7.824.$$
$$\text{For } i = 12\%\ (P \longrightarrow A, 12\%, 16) = 6.974.$$

By interpolation,

$$i\% \simeq 10\% + \left(\frac{7.82 - 7.14}{7.82 - 6.97}\right)2\% = 11.6\%.$$

2.12 PRESENT WORTH COMPUTATIONS

Proposed investments are feasible only if they can be recovered with interest. The interest rate should be at least as large as that which is attractive to the investor under the particular set of circumstances. In what follows this interest will be called the attractive rate of return.

The first method to be discussed for comparing alternative investment situations consists of reducing series of estimated money receipts and disbursements to their present worth as of the zero date of the series being compared.

Because first costs are already at zero date, no interest factors need be applied to them. In a cost situation, present worth of salvage values must be subtracted to obtain the present worth of the net disbursements. Present worth computations also serve to place a value on prospective net money receipts and, as will be shown later, are used to compute true rates of return.

In accounting circles, reduction to present worth is called discounting.

Example 15:

An architect is faced with the following alternatives for providing on-site power generation to a hospital:

Alternative A

1. Purchase equipment to supply an expanded 500-bed hospital facility at a cost of \$250,000.
2. The expected life of the equipment is 25 years with zero salvage value.
3. Maintenance and operating costs are estimated at \$30,000 per year.

Alternative B

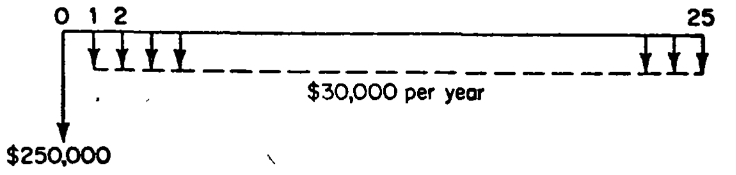
1. Purchase equipment package No. 1 today at a cost of \$150,000 to supply the needs of a 250-bed facility.
2. Ten years hence, buy equipment package No. 2 at an estimated cost of \$200,000 to supply the hospital facility expanded to 500 beds.
3. The expected life of each equipment package is 25 years. However, equipment 15 years old can be sold at an estimated price of \$50,000.

4. Maintenance and operating costs are estimated at \$18,000 per year for each equipment package.

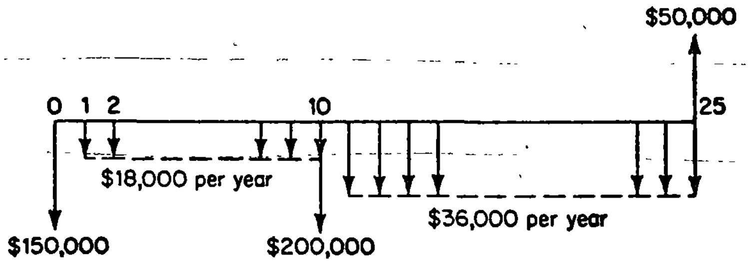
The architect wishes to select the least costly alternative assuming a minimum attractive rate of return of 8% per annum.

Solution:

The cash flow diagrams for each alternative are given below:



ALTERNATIVE A



ALTERNATIVE B

The computations of present worth (P.W.) are carried out as follows:

Alternative A

Initial Investment	= \$250,000
P.W. of Annual Disb., years 1 to 25	
= 30,000($P \longrightarrow A$, 8%, 25) = 30,000(10.675)	= \$320,000
Total P.W.	= \$570,000

Alternative B

Initial Investment	= \$150,000
P.W. of Annual Disb. of \$18,000, years 1 to 10	
= 18,000($P \longrightarrow A$, 8%, 10) = 18,000(6.710)	= \$121,000
P.W. of \$200,000, 10 years hence	
= 200,000($P \longrightarrow F$, 8%, 10) = 200,000(0.4632)	= \$ 92,600
P.W. of Annual Disb. of \$36,000, years 11 to 25	
= 36,000($P \longrightarrow A$, 8%, 15)($P \longrightarrow F$, 8%, 10)	
= 36,000(8.559)(0.4632)	= \$143,000
Total P.W.	= \$506,600
Less P.W. of salvage value	
= 50,000($P \longrightarrow F$, 8%, 25) = 50,000(0.1460)	= \$ 7,300
P.W. of *Net* Disbursements	= \$499,300

Consequently, Alternative B is more economical.

Comment on Example 15:

1. It was previously stated that in computing present worth it is necessary to establish the attractive rate of return. This is the rate at which money could be profitably invested in an alternate venture. Naturally, this rate should not be less than the cost of borrowed money and, in general, should be higher.
2. Under Plan B, the reduction to present worth of the \$36,000 annual disbursement from years 11 to 25 was accomplished as follows:
   a. First, the series was reduced to P.W. at year 10

   $$= 36{,}000(P \longrightarrow A,\ 8\%,\ 15) = P_{10}.$$

   b. Then this sum of money at year 10 was reduced to present worth at year zero

   $$= P_{10}(P \longrightarrow F,\ 8\%,\ 10) = \$143{,}000.$$

   c. The calculation was performed in one operation, thus

   $$36{,}000(P \longrightarrow A,\ 8\%,\ 15)(P \longrightarrow F,\ 8\%,\ 10)$$
   $$= 36{,}000(8.559)(0.4632) = \$143{,}000.$$

2.12.1 Alternatives with Perpetual Lives

There are cases when a present worth study must be done for an alternative with a long service life (50 years or more) or for one with a perpetual period of service. Economy studies are, in general, not sensitive to cash flow in the distant future, unless the interest rate is very low. For example, the present worth of one dollar 50 years hence at 4% interest is only fourteen cents. At 8% interest, it is only two cents. Present worth computed for a perpetual period is called *capitalized* costs. Capitalized costs are simply annual costs divided by the interest rate.

Example 16:

What is the present worth of an annual receipt of \$450, forever, if the attractive rate of return is 8%?

Solution:

The question can be rephrased as follows: How much money P should be invested at 8% to yield annual receipts of \$450 without ever touching the principal (that is, forever)?
The solution is obvious.

$$0.08\,P = 450.$$

That is, 8% of P must equal \$450 each year. Thus,

$$P = \frac{450}{0.08} = \$5{,}620.$$

If \$5,620 is deposited in a savings account paying 8% annual interest,

$450 can be withdrawn every year, forever, without depleting the original amount. Consequently, the present worth of $450 annually, in perpetuity, is $5,620 at 8%.

Example 17:

Determine the difference in present worth of the following two plans.

Plan C

Initial Cost	= $50,000
Annual Cost	= $ 2,000
Service Life	= 25 years
Interest Rate	= 0.08

Plan D

Assume that Plan C will continue in perpetuity—that is, every 25 years there will be an investment of $50,000 and the annual costs will remain at $2,000, forever.

Solution:

Plan C

Initial Cost	= $50,000
P.W. of Annual Disb., years 1 to 25	
$= 2{,}000(P \longrightarrow A, 8\%, 25) = 2{,}000(10.675)$	= $21,400
Total P.W.	= $71,400

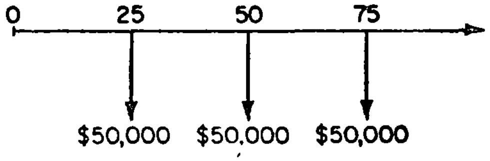
Plan D

Initial Cost	= $50,000
P.W. of Annual Disb., forever	
$= 2{,}000 \div 0.08$	= $25,000
P.W. of 50,000 every 25 years, forever	
$= 50{,}000(A \longrightarrow F, 8\%, 25) \div 0.08$	
$= 50{,}000(0.01368) \div 0.08$	= $ 8,550
Total P.W.	$83,550

Comment on Example 17:

1. The present worth of $50,000 every 25 years, forever, is computed as follows

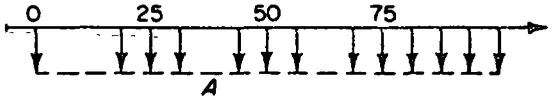
   a.



First, reduce the $50,000 to an equivalent annual cost by multiplying it by the sinking fund factor for each 25-year period,

$A = \$50{,}000\,(A \longrightarrow F, 8\%, 25).$

b.



Now that the equivalent annual cost to a $50,000 disbursement every 25 years has been computed, divide that annual cost by the interest rate, as in Example 16, to obtain

$\text{P.W. } \$50{,}000\,(A \longrightarrow F, 8\%, 25) \div 0.08 = \$8{,}550$

2. Plan D is, in fact, a perpetually cycling Plan C. The difference in present worth between the two plans is $12,150—an increase of only 17% between 25 years of life and perpetual service.

2.12.2 Alternatives with Different Lives

In order to provide an unbiased comparison between alternatives with different lives, it is necessary to transform them, somehow, into alternative plans supplying the needed service for the *same* number of years.

Because distant disbursements and receipts have little effect upon present worth computations at normal interest charges (4% or higher), a convenient simple assumption to make is that replacement assets will repeat the costs forecasted for the initial assets.

Example 18:

Compare the following plans at 6% interest.

Plan E

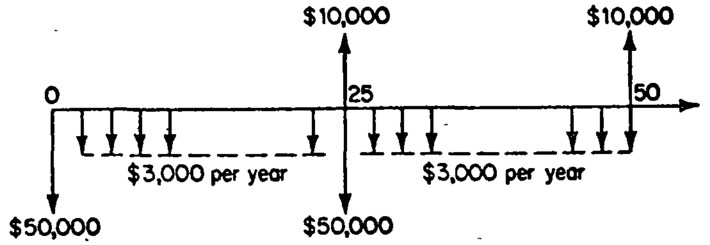
Initial Equipment Cost	= $50,000
Annual Cost of Oper. & Maint.	= $ 3,000
Service Life	= 25 years
Salvage Value	= $10,000

Plan F

Initial Equipment Cost	= $75,000
Annual Cost of Oper. & Maint.	= $ 2,500
Service Life	= 50 years
Salvage Value	= 0

Solution:

The first step is to make the service life of Plan E 50 years by assuming that the costs will be repeated during the second 25-year cycle. Thus the cash flow diagram for Plan E becomes



Plan E

Initial Cost	= $50,000
P.W. of Annual Disb. years 1 to 50	
= 3,000(*P* → *A*, 6%, 50) = 3,000(15.762)	= $47,300
P.W. of Net Cost 25 years hence	
= (50,000 − 10,000)(*P* → *F*, 6%, 25)	
= 40,000(0.233)	= $ 9,300
Total P.W.	= $106,600
Less P.W. of Salvage Value 50 years hence	
= 10,000(*P* → *F*, 6%, 50) = 10,000(0.0543)	= $ 540
P.W. of Net Disbursements	= $106,060

Plan F

Initial Cost	$ 75,000
P.W. of Annual Disb., years 1 to 50	
= 2,500(*P* → *A*, 6%, 50) = 2,500(15.762)	= $ 39,400
Total P.W.	= $114,400

On the surface, Plan E is more economical; however, there are additional considerations:

1. The cost of the equipment 25 years hence for Plan E may be much higher than the $50,000 assumed.
2. On the other hand, technological breakthroughs may make the present equipment less desirable or obsolete and, consequently, the shorter life of Plan E may turn out to be a blessing in disguise.

Considerations such as these fall in the realm of unquantifiable factors. The function of management is to make the right decision after having looked into the hard figures as well as the imponderables. Long-range planning results in economical decisions when the forecasts for company growth and other factors are essentially correct. Being a good manager (decision maker) is a very difficult, demanding task.

2.12.3 A Warning About Present Worth Computations

Although municipal engineers and other professionals involved in public works projects have used capitalized costs for many years (long-lived structures), a common error in present worth computations is that of assuming a perpetual life when the situation is otherwise. Also, interest rates used in present worth computations are frequently too low and do not reflect the true cost of money.

2.12.4 Establishing Bond Valuations

Suppose that a 4%, $15,000 government bond is due after 20 years. The bond calls for a semiannual payment of $300 and of $15,000 at the end of the 20-year period. If the bond is to be valued to yield a nominal 6% compounded *semiannually*, what should its purchase price be? The value of the bond is the present worth of the interest payments of $300 every six months plus the principal payment of $15,000, 20 years from today, at 3% interest per six-month period (6% annual interest).

P.W. of semiannual payments, periods 1 to 40	
= 300(*P* → *A*, 3%, 40) = 300(23.115)	= $ 6,934.50
P.W. of principal payment	
= 15,000(*P* → *F*, 3%, 40) = 15,000(0.3066)	= $ 4,599.00
Value of bond to yield a nominal 6% compounded semiannually	= $11,533.50

The effect of bond ownership on the payment of income taxes should be carefully studied. Published tables of bond values give the relationship between price and yield for bonds with several coupon rates and years to maturity.

2.13 EQUIVALENT UNIFORM ANNUAL CASH FLOW

The second procedure to be discussed for comparing cash flow through time is the so-called equivalent uniform annual cash flow method. Nonuniform series of money receipts and disbursements are transformed into equivalent uniform series by applying the proper compound interest factors.

Once the present worth of an investment plan has been computed, its equivalent annual cash flow value can be obtained immediately by multiplying the present worth by the capital recovery factor. By the same token, equivalent uniform annual cash flow can be converted to present worth by multiplying the present worth by the capital recovery factor. Whichever alternative is favored by one of the methods must also be favored by the other, and in the same proportion.

Example 19:

What are the equivalent uniform annual cash flows of the plans given in Example 18?

Solution:

The equivalent uniform annual costs can be computed from the present worths.

Plan E

$i = 0.06$, $n = 50$ years	
P.W. of Plan E	= \$106,060.
Equivalent Uniform Annual Cost	
= 106,060($A \longrightarrow P$, 6%, 50)	
= 106,060(0.06344)	= \$6,720 per year.

Plan F

$i = 0.06$, $n = 50$ years	
P.W. of Plan F	= \$114,400.
Equivalent Uniform Annual Cost	
= 114,400($A \longrightarrow P$, 6%, 50)	
= 114,400(0.06344)	= \$7,250 per year.

The equivalent uniform annual costs can also be computed directly from the data. The different service lives of Plan E (25 years) and Plan F (50 years) no longer have to be made the same when using the equivalent annual cash flow method. However, the assumption is implied that the annual cost of service for the shorter lived alternative will continue the same for the additional number of years of service provided by the longer lived alternative.

Plan E

Equivalent Annual Cost of Initial Cost	
= 50,000($A \longrightarrow P$, 6%, 25) = 50,000(0.07823)	= \$3,900
Annual Disbursements, years 1 to 25	= \$3,000
Less Equivalent Annual Cost of Salvage Value, 25 years hence	
= 10,000($A \longrightarrow F$, 6%, 25) = 10,000(0.01823)	= \$-180
Equivalent Uniform Annual Cost	= \$6,720

Plan F

Equivalent Annual Cost of Initial Cost	
= 75,000($A \longrightarrow P$, 6%, 50) = 75,000(0.6344)	= \$4,750
Annual Disbursements, years 1 to 50	= \$2,500
Equivalent Uniform Annual Cost	\$7,250

Comment on Example 19:

1. The equivalent uniform annual costs computed both ways are the same, as should be expected.
2. Only capital costs require conversion to uniform series by the appropriate compound interest factors.
3. In transforming the salvage value to equivalent uniform annual receipts for Plan E, the sinking fund factor was used because the salvage value occurs in the future. Several formulas for reducing salvage values can be derived; however, the method used in Example 19 is adequate and is the one adopted for future computations.

2.13.1 Difference in Annual Cost Between Long Life and Perpetual Life

As the number of years, n, increases, the capital recovery factor $(A \longrightarrow P, i\%, n)$ approaches the interest rate i.

From Equation (2.20),

$$(A \longrightarrow P, i\%, n) = \frac{i}{(1+i)^n - 1} + i.$$

Therefore,

$$\lim_{n\to\infty}(A \longrightarrow P, i\%, n) = i \tag{2.36}$$

because the denominator of the fraction increases without bound, thus making the fraction vanish in the limit.

For example,

$$(A \longrightarrow P, 6\%, 100) = 0.06018 \simeq 0.06 = i.$$

This concludes the discussion of the second method presented for comparing alternative cash flows.

2.14 TRUE RATE OF RETURN COMPUTATIONS

The true rate of return of an investment is the interest rate at which the present worth of the *net* cash flow is zero. It is determined by using trial-and-error computations. Straight line interpolation between tabulated rates of interest is considered to give enough accuracy for most applications of interest.

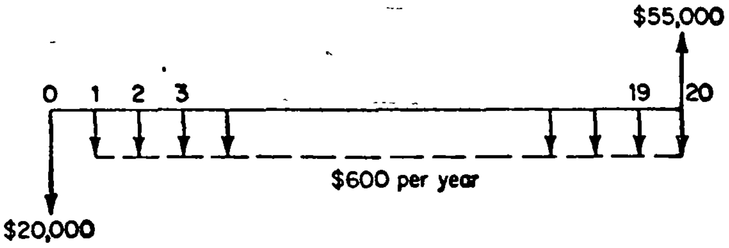
Cash flow analyses of the type being discussed in this book make management aware of the economic value of time; money today is more valuable than money in the distant future. It also makes management cognizant of the fact that in business situations cash flow is what matters and that income taxes, their amount and timing, play an important role in business decisions for they have a very marked effect upon cash flow.

Example 20:

A parcel of land was bought 20 years ago for \$20,000 and sold today for \$55,000. Through the years the average property tax paid annually amounts to \$600. What is the true rate of return yielded by this investment?

Solution:

The cash flow diagram is



The true rate of return is determined by trial and error, as follows:

For i = 0.03 (3% interest)

Initial Investment	= $-20,000
P.W. of $600 Annual Disb., years 1 to 20	
= 600($P \longrightarrow A$, 3%, 20) = 600(14.877)	= $ -8,930
P.W. of Disbursements	= $-28,930
P.W. of $55,000 receipt 20 years hence	
= 55,000($P \longrightarrow F$, 3%, 20) = 55,000(0.5537)	= $+30,400
P.W. of Receipts	= $+30,400
P.W. of Net Cash Flow = +30,400 − 28,930	= $ +1,470

Because the P.W. of the net cash flow turned out to be positive the interest rate must be higher.

Try i = 0.035 (3.5% interest)

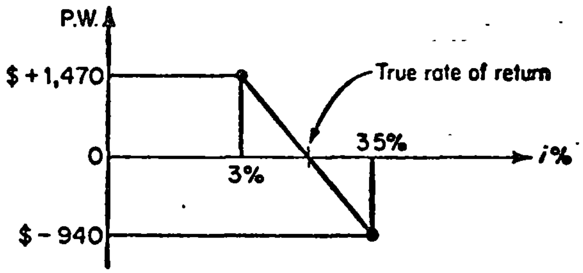
Initial Investment	= $-20,000
P.W. of $600 Annual Disb., years 1 to 20	
= 600($P \longrightarrow A$, 3.5%, 20) = 600(14.212)	= $ -8,540
P.W. of Disbursements	= $-28,540
P.W. of $55,000 receipt 20 years hence	
= 55,000($P \longrightarrow F$, 3.5%, 20) = 55,000(0.5026)	= $+27,600
P.W. of Receipts	= $+27,600
P.W. of Net Cash Flow = +27,600 − 28,540	= $ -940

The P.W. of the net cash flow is now negative. This indicates that the true rate of return is between 3% and 3.5%. From a linear interpolation (See Figure 2.5), find

$$i\% = 3\% + \left(\frac{1,470}{1,470 + 940}\right)0.5\% = 3.3\%$$

Thus, the true rate of return from this land investment is a modest 3.3%. The linear interpolation is usually valid to the nearest tenth of a percent.

FIGURE 2.5 Linear Interpolation to Determine True Rate of Return.



2.14.1 Equivalent Uniform Annual Cash Flow Method

Equivalent uniform annual cash flow can be used to compute the true rate of return. The definition which applies to this method is: True rate of return is the interest rate at which the equivalent uniform annual *net* cash flow is zero. Whichever method is used, the results will be identical (except for round-off error).

The rate of return computation is given different names by different analysts: discounted cash flow method, investors method, interest rate or return, profitability index, and so on. All of them follow the same basic procedure. However, the reader is warned to look out for many incorrect—sometimes deceivingly so—methods of computing so-called rates of return.

2.14.2 Alternatives with Different Lives

As in the case of present worth computations, the lives of the competing alternatives must be equalized, as explained previously, before computing their true rates of return.

Example 21:

Table 2-2 shows receipts and disbursements on income property from the

TABLE 2.2. Cash Flow of Income Property.

Year	*Disbursements*	*Receipts*	*Net Cash Flow*
0	$-19,000	0	$-19,000
1	-2,000	$ +2,500	+500
2	-1,500	+2,500	+1,000
3	-1,200	+2,800	+1,600
4	-1,800	+2,800	+1,000
5	-800	+3,000	+2,200
6	-1,200	+3,000	+1,800
7	-1,700	+3,200	+1,500
8	-2,000	+27,000	+25,000
			$+15,600

time it was bought to its sale 8 years later. Compute the rate of return on the investment.

Solution:

Note that the sum of column four in Table 2.2 is \$15,600. This is the present worth of the net cash flow at 0% interest. Only if this column yields a positive value has the investment been profitable. In fact, if the net cash flow column summed to zero the investment would have yielded a zero rate of return. To determine the true rate of return, set up the following table for the trial-and-error computations:

Year	*Net Cash Flow*	*(P ⟶ F, 8%, n)*	*P.W. at 8%*	*(P ⟶ F, 10%, n)*	*P.W. at 10%*
0	\$−19,000	1.0000	\$−19,000	1.0000	\$−19,000
1	+500	0.9259	+460	0.9091	+450
2	+1,000	0.8573	+860	0.8264	+830
3	+1,600	0.7938	+1,270	0.7513	+1,200
4	+1,000	0.7350	+740	0.6830	+680
5	+2,200	0.6808	+1,500	0.6209	+1,370
6	+1,800	0.6302	+1,130	0.5645	+1,020
7	+1,500	0.5835	+880	0.5132	+770
8	+25,000	0.5403	+13,500	0.4665	+11,700
	\$+15,600		\$ +1,340		\$ −980

$$\text{Therefore, the rate of return} = 8\% + \left(\frac{1{,}340}{1{,}340 + 980}\right)2\% = 9.1\%.$$

2.15 BENEFIT-COST RATIO

The fourth and final method of alternative evaluation discussed in this book is the benefit-cost ratio. This approach was born out of the Flood Control Act of 1936 which stipulates that "benefits to whom-soever they may accrue" should exceed "estimated costs." Identical conclusions concerning the worthiness of alternative investment plans are reached with the benefit-cost ratio as with present worth, equivalent uniform annual cash flow, or rate of return computations.

2.15.1 Calculation of Benefit Costs

Let $B =$ Benefits,
$D =$ Disbenefits,
and $C =$ Costs.

Then the stipulation that $B - (C + D) > 0$ is also expressible $B - D/C > 1$. However, in the ratio computation it makes a great deal of difference whether an item is classified as a disbenefit or as a cost. In the first case, the item is subtracted from the benefit figure on the numerator; in the second, it is added to the cost figure in the denominator. This same consideration does not affect the difference approach to benefit cost. The benefit-cost computations yield the same results whether they are obtained from present worth or from equivalent uniform annual values.

Example 22:

Consider a public works project with estimated benefits of \$1,600,000 and costs of \$650,000. In addition, assume that there exists an adverse item valued at \$200,000. Then,

$$\begin{aligned} B - (C + D) &= 1{,}600{,}000 - (650{,}000 + 200{,}000) \\ &= \$750{,}000 \end{aligned}$$

whether or not the adverse item is considered a cost or a disbenefit. On the other hand, for the ratio computation:

1. Assume that the \$200,000 is a cost, then

$$\frac{B}{C} = \frac{1{,}600{,}000}{850{,}000} = 1.88.$$

2. If the \$200,000 is assumed to be a disbenefit, obtain

$$\frac{B - D}{C} = \frac{1{,}600{,}000 - 200{,}000}{650{,}000} = 2.15.$$

The project appears to have different merits according to which decision is made. The benefit-cost ratio can also lead to incorrect, even catastrophic, conclusions when used improperly or in situations where it is not relevant, such as in warfare, countless social problems, and many business situations.

Example 23:

A municipality is studying the worthiness of constructing a large airport facility. The estimated cost of all improvements is \$35,000,000, to be financed with sales taxes and through landing fees and other income generated by the airport. The municipality plans to float a \$35,000,000, 5% bond issue payable, with interest, during the life of the facility. Benefits to the community are in the form of increased tourism, industrial expansion, business upturn, and other intangibles which have been estimated to generate an increase in income of approximately \$4,000,000 per year, in perpetuity. The decision makers decide to use the benefit-cost ratio, based on present worth computations at 5% interest, to evaluate the proposed plan.

P.W. of Benefits, in perpetuity
= 4,000,000 ÷ 0.05 = \$80,000,000
P.W. of Costs = \$35,000,000

$$\text{Benefit-Cost Ratio} = \frac{80{,}000{,}000}{35{,}000{,}000} = 2.28$$

This ratio is excellent provided that the municipal government does not overextend itself to the detriment of other programs such as education, transportation, law enforcement, sanitation, and other vital services.

The references cited at the end of the chapter are excellent sources of additional information to the reader interested in pursuing further the topics discussed.

EXERCISES

2-1. What is the effective rate of a nominal 8% annual interest paid
  a. semiannually?
  b. quarterly?
  c. monthly?

2-2. If \$2,500 is deposited in a savings account on December 31, 1971, how much money would have accumulated by December 31, 1985, if interest is 5% compounded semiannually?

2-3. How much would have to be invested at 8% today to recover \$20,000 six years hence?

2-4. What should the quarterly notes be on a loan of \$8,000 to be repaid in 5 years at a nominal 8% annual interest?

2-5. Mr. Smith wants to subscribe to a savings plan returning 6% annual interest. He wishes to prepare to meet the expenses of his son's college education for which he anticipates the need of \$15,000 ten years from today. How much should Mr. Smith deposit every year in the savings account?

2-6. How much money should a wealthy industrialist donate to set up in perpetuity a \$30,000 per year university chair if the money can be safely invested at 4%?

2-7. What is the maximum amount of money that can be withdrawn in equal amounts at the end of 1985, '86, '87, and '88 from a savings account paying 6% interest if deposits of \$1,500 each were made at the end of 1971, '72, and '73?

2-8. What is the present worth in 1971 of a uniform series of \$2,000 receipts from 1990 through '99 (10 years) if interest is 3.5%?

2-9. How much should be invested today at 10% to withdraw \$5,000, 5 years hence; \$10,000, 8 years from today; and \$9,000, 10 years from today and completely deplete the investment?

2-10. Use present worth computations at 6% annual interest to determine the most economical of the plans given below.

Item	Plan A	Plan B	Plan C
First Cost	\$25,000	\$50,000	\$35,000
Annual Oper. & Maint.	\$ 3,000	\$ 2,000	\$ 2,500
Salvage Value at End of Life	\$ 5,000	\$ 7,000	\$ 6,000
Life	10 years	30 years	15 years

2-11. Mr. Jones wishes to determine the approximate value of income property based on a present worth computation at 8% interest (his minimum attractive rate of return). Annual receipts (including the effect of depreciation on income taxes) are, on the average, \$20,000. Disbursements amount to \$5,000 per year. Jones wishes to hold the property seven years, at which time he expects to sell it for a net \$150,000 after the payment of long-term capital gains. What is the maximum purchase price Mr. Jones can afford to pay to meet his investment objectives?

2-12. Determine the better of the following two plans using present worth computations at 5% interest.

Year(s)	Receipts	Disbursements	Receipts	Disbursements
0	0	\$-150,000	0	\$-300,000
1-20	\$ +15,000	-3,000	\$ +25,000	-4,000
21	+15,000	-4,000	+25,000	-4,000
22	+15,000	-5,000	+25,000	-4,000
23	+15,000	-5,000	+25,000	-4,000
24	+15,000	-6,000	+25,000	-4,000
25	+15,000	-186,000	+25,000	-54,000
26–49	+20,000	-2,000	+30,000	-5,000
50	+40,000	-2,000	+60,000	-5,000
	\$+895,000	\$-466,000	\$+1,405,000	\$-575,000

2-13. Use the equivalent uniform annual cost method at 7% interest to solve problem 2-10.

2-14. Use the equivalent uniform annual cash flow method at 4% interest to solve problem 2-12.

2-15. Compute the true rate of return of Plan D in problem 2-12.

2-16. Compute the true rate of return of Plan E in problem 2-12.

2-17. Assume a \$100,000 purchase price for the property in problem 2-11. What is Mr. Jones's true rate of return on this seven-year investment venture?

2-18. The Department of Public Works is considering a project with a cost of \$2,000,000; resulting benefits valued at \$5,500,000; and a \$75,000 adverse item.
   a. Compute the benefit-cost ratio for the project with the adverse item considered as a cost.
   b. Compute the benefit-cost ratio with the adverse item taken as a disbenefit.

2-19. Compare plans D and E in problem 2-12 using the benefit-cost ratio computed on present worth at 3.5% interest.

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CHAPTER 3

The Differential Approach to Optimization

3.1 PRELIMINARY CONCEPTS

The typical problem in optimization is expressed by an objective function of n independent variables

$$y(x_1, x_2, \ldots, x_n) \tag{3.1}$$

that is to be maximized or minimized—in general, optimized—subject to a set of constraints written in the form of equations and inequalities,

$$\begin{aligned} f_i(x_1, \ldots, x_n) &= 0 \quad \text{for } i = 1, \ldots, m; \\ f_i(x_1, \ldots, x_n) &\leq 0 \quad \text{for } i = m+1, \ldots, r; \\ f_i(x_1, \ldots, x_n) &\geq 0 \quad \text{for } i = r+1, \ldots, p. \end{aligned} \tag{3.2}$$

Points satisfying the constraints collectively form the problem's feasible region F.

If equalities are possible for all constraints, F is said to be closed; otherwise, F is open.

For reasons that will become apparent in Chapter 5, problems must be formulated with closed regions whenever possible.

CHAPTER 6

Linear Programming Applications to Planning

Two examples of the application of linear programming models to architecture and planning are given in this chapter. These examples come from papers originally published by the author in collaboration with Messrs. James E. Hand and Raul S. Gonzalez. The complete references appear at the end of the chapter.

6.1 A GENERALIZED LINEAR MODEL FOR OPTIMIZATION OF ARCHITECTURAL PLANNING

6.1.1 Introduction

In the realm of architectural planning, there exists a type of problem which designers frequently confront when financial return is the most appropriate measure of the system's effectiveness. In this category can be included all rental and speculative housing (single and multiple family dwellings), office buildings, warehouses, stores, many industrial facilities, and so on, and building complexes which combine some or all of these to provide comprehensive services to the tenant.

Traditionally, the problem of planning for capital investment has been handled in a semiempirical way, in which the data serving as basis for decision making may be more or less reliable and up to date, but with the processing of these data (to arrive at the optimum allocation of space for maximum expectation of financial return) entirely intuitive and consequently unreliable. Once the pertinent data are collected, the most profitable design configuration can be ascertained through the optimization of a linear model which incorporates the most salient features of the real life, planning situation.

The model developed in the following section takes into account multiuse facilities and considers realistic design constraints such as zoning regulations, parking requirements, and so on. An example problem is also presented to illustrate application of the theory.

6.1.2 The Model

6.1.2.1 Definition of Terms

The design of buildings and other architectural facilities for financial return is constrained by many internal and external factors such as budget, market restrictions (construction costs, rentability, individual preferences), parking regulations, lot coverage, and so on, in addition to environmental factors, many of which defy quantification.

The procedure described in this section attempts to consider as many as possible of the quantifiable factors in optimizing architectural planning within the framework of economics: return on invested capital.

With the information extracted from the model (a type of *simulation* model, in many respects), rational decisions can be formulated based upon knowledge of the most recent tax depreciation structure, maintenance costs, alternative investment opportunities, and so on.

Let x_{ij}^k be the *floor area* of facility type i, at level j, of architectural quality k.

The "type i facility" refers to the use made of the space considered; offices, apartments, stores, warehouses, laboratories, industrial facilities, classrooms, and so on.

The "j level" denotes the location of the facility; first, second, . . . , nth floor level.

The "k quality" refers to the degree of architectural refinement of the space: types of finishes, environmental control, and many other considerations, the effects of which are reflected in the cost of construction and in the rentability of the facility.

Similarly, let

c_{ij}^k = *cost* per unit of area of facility i, at level j, of architectural quality k.
r_{ij}^k = *rent* per unit of area, per unit of time, from facility i, at level j, and architectural quality k.
p_{ij}^k = *probability of renting or selling* facility i, at level j, and architectural quality k.

and

q_{ij}^k = *probability of not renting or selling* facility i, at level j, and architectural quality k. Hence, $p_{ij}^k + q_{ij}^k = 1$.

It will be assumed that the market is large, and that for the time period under consideration it is in a steady state condition, such that the introduction of additional facilities for rent or sale will *not* significantly affect the parameters defined above.

6.1.2.2 Mathematical Formulation

The total expected rent per unit of time can be expressed as follows:

$$E(R) = \sum_{k=1}^{L} \sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij}^k r_{ij}^k x_{ij}^k. \tag{6.1}$$

This is the objective function to be maximized, subject to constraints of the types described below.

1. *Market*

a. A survey may reveal that, within a specified geographic region, there exist vacancy rates for some or all of the proposed facilities. These vacancy rates are, in fact, the $q_{ij}^k = 1 - p_{ij}^k$ which were already considered in the formulation of the objective function. Nevertheless, the q_{ij}^k should be compared with the upper limits set on them by banks and other funding institutions. If these limits are exceeded, the project may be very difficult if not impossible to finance. Therefore,

$$q_{ij}^k \le (q_i^k)\max, \tag{6.2}$$

for all i and k.

b. *Market preferences* data may indicate that the area of each facility type and quality must not exceed a certain fraction of the total building area. Let f_i^k be upper bounds to the area ratios; then the constraints can be written,

$$\sum_j x_{ij}^k \le f_i^k\Big(\sum_{k=1}^{L} \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}^k\Big) + e_i^k, \qquad i = 1, 2, \ldots, m; \quad x = 1, 2, \ldots, L. \tag{6.3}^*$$

In general,

$$\sum_{k=1}^{L} \sum_{i=1}^{m} f_i^k > 1 \tag{6.4}$$

because of the requirement that the f_i^k be upper bounds to the area ratios.

The e_i^k are small positive constants introduced into the constraint equations and inequalities to avert degeneracy.

2. *Zoning regulations* such as:

a. *Maximum building coverage* of total lot area which can be mathematically expressed as follows,

$$\sum_k \sum_i x_{ij}^k \le A_j, \qquad j = 1, 2, \ldots, n, \tag{6.5}$$

where A_j = maximum allowable building area of floor level j.

b. *Height restrictions* which could be overall building restrictions such that $j \le n$ or restrictions on each individual facility; merchandising space, for example, should be located on lowest floors, and so on.

c. *Off-street parking* regulations, usually given as the number, n_i, of parking stalls per building area, a_i, of facility type i. In addition, the area, a, required for each car for parking, drives, and so on, can be easily computed and the off-street, surface parking restriction expressed as,

$$a\left[\sum_{i=1}^{m} \frac{n_i}{a_i}\left(\sum_{k=1}^{L} \sum_{j=1}^{n} x_{ij}^k\right)\right] \le A_t - \sum_k \sum_i x_{i1}^k, \tag{6.6}$$

where A_t = total buildable lot area (total lot area minus area required for landscaping, street rights of way, utility easements, set back restrictions, topographically unsuitable land, etc.).

Note that $(A_t - \sum_k \sum_i x_{i1}^k)$ is the site area available for parking (A_t minus first floor area of building).

3. *Design decisions* (massing studies). These decisions are made by designers for aesthetic and other reasons and are often arbitrary. Nevertheless, their effect upon the economic health of the system can be measured by comparing

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* The range of the sum on the left-hand side of inequality (6.3) varies for each facility type and quality and for this reason it is not given explicitly. This convention will be used for the rest of this chapter.

all optimal solutions from models with different sets of design constraints to one having *no* design constraint. The model without design constraints yields the *global optimal solution*. The massing associated with the global optimal solution may not be aesthetically and/or structurally acceptable and it is at this point that design constraints must be introduced. The constrained model will, in general, yield a lower value of the objective function. Thus, if $E(R)_0$ is the global optimal rent and $E(R)_c$ is the expected rent when the problem is constrained by design considerations,

$$E(R)_c = E(R)_0 - C_c, \tag{6.7}$$

where C_c is the cost of the design decisions. It should be realized that aesthetic values may affect the four parameters c^k_{ij}, r^k_{ij}, p^k_{ij}, and q^k_{ij}, as well as others. If their effect is known, the parameters should be modified accordingly and a new $E(R)_c$ computed.

The ability to ascertain the effect of design decisions upon the system's economic health is a most valuable characteristic of the model, for it measures indirectly the "cost" of beauty and of other aesthetic factors; it represents an attempt to quantify some of the intangibles of architecture and urban planning. Design constraints may take different mathematical forms, depending upon the massing restrictions. If, for example, the planner decides that the building should take the form of a tower with a spread-out, s story base, b times or more larger than each of the tower's floors, the constraints would be written thus:

$$\sum_k \sum_i x^k_{i(s+1)} \le \frac{1}{b}\Big(\sum_k \sum_i x^k_{i1}\Big) + e_{s+1}, \tag{6.8}$$

$$\sum_k \sum_i x^k_{ij} = \sum_k \sum_i x^k_{i1} + e_j, \qquad j = 2, 3, \ldots, s, \tag{6.9}$$

$$\sum_k \sum_i x^k_{ij} = \sum_k \sum_i x^k_{i(s+1)} + e_j,\ j = s + 2, s + 3, \ldots, n. \tag{6.10}$$

The $e_j, j = 2, \ldots, n$, are, again, small positive constants introduced to avert degeneracy. Many other types of design decisions can be similarly formulated.

4. *Budget*, generally expressed as a fixed amount of money, B, which must not be exceeded by all fees and construction costs, excluding the cost of land.

Construction costs for each facility type and quality are, in general, functions of the total number of floors. Specifically, as the number of floors in the building increases, the costs per units of area could decrease or increase. This variability is not usually too sensitive and can be conveniently expressed as a cost multiplier, step function of the total number of floors, n. Let $\beta^k_{ij}(n) \ge 0$ be such step function. Graphically, it could be typically mapped as in Figure 6.1.

The figure shows that $\beta^k_{ij}(n)$ decreases for $(\alpha^k_{ij})_2 \le n < (\alpha^k_{ij})_3$. It further decreases for $(\alpha^k_{ij})_3 \le n < (\alpha^k_{ij})_4$. Then it increases in the interval $(\alpha^k_{ij})_4 \le n < (\alpha^k_{ij})_5$, and the increase is even greater for $(\alpha^k_{ij})_5 \le n \le (\alpha^k_{ij})_6$. These latter increases would reflect the higher costs of foundation and vertical transportation, for example. When $n > (\alpha^k_{ij})_6$, the cost multiplier becomes infinite, denoting that $(\alpha^k_{ij})_6$ is the upper bound to the number of floors due to zoning restrictions or other considerations. The variation shown in Figure 6.1 is, of course, only one of an infinite number of possibilities, but all of them will exhibit the same general shape.

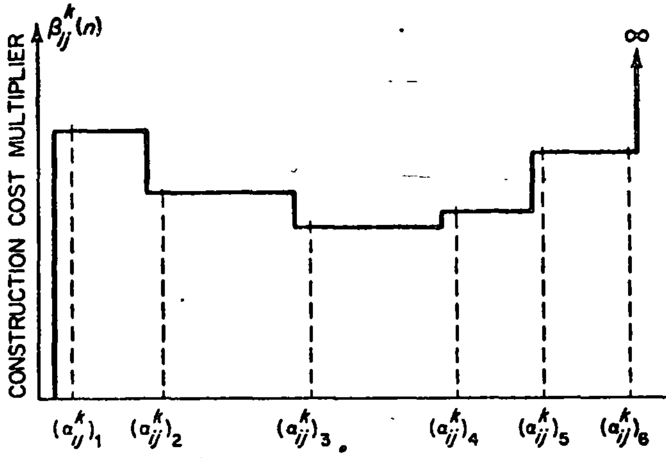

FIGURE 6.1. Total Number of Floors.

In general, there will be $n \times m \times L$ construction cost multipliers with a proportionate number of $(\alpha^k_{ij})_q$ nodes where changes in the costs occur. Let the nodes be ordered sequentially for all $\beta^k_{ij}(n)$ and renumbered γ_q, $q = 1, 2, 3, \ldots, r$. Then a typical cost multiplier, step function of n, would appear as given in Figure 6.2. This relabeling is necessary to show, for each $\beta^k_{ij}(n)$ multiplier, all points at which construction costs change for any type, level, and quality of facility, thus affording complete control upon the optimization process.

The cost multiplier functions, however, introduce a further complication in the model because the number of floors may not be known a priori. This is, in fact, a nonlinear characteristic of the system that, in this context, exhibits recycle loops. A method will be given later on for handling the nonlinearity in a satisfactory, linear manner. Additional items of cost and cost coefficients must be defined; for example:

a. *Cost of subsurface exploration*, soil investigation, foundation recommendations, and report. Usually given as a lump sum, b_s.
b. *Architectural-engineering fees*, usually expressed as a percentage of total construction costs by a decimal coefficient, c_a.

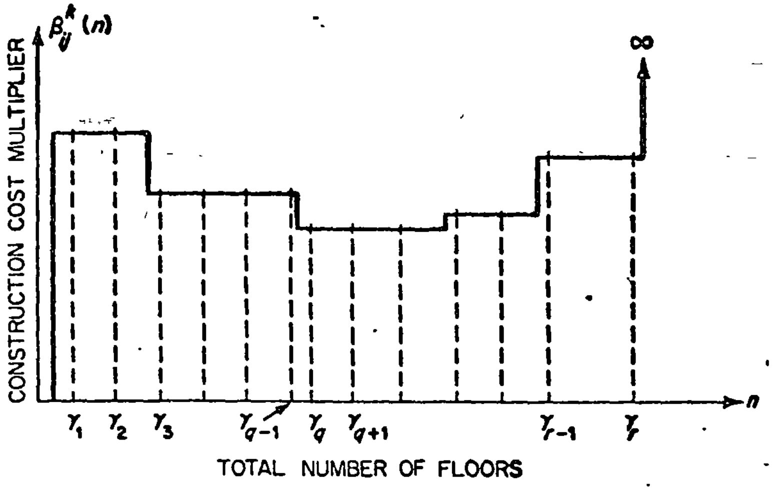

FIGURE 6.2. Total Number of Floors.

c. *Fund for contingencies*, also expressed as a percentage of total construction costs. Let c_c be the decimal equivalent of that percentage.

d. *Cost of movable furniture*, expressed as a percentage of construction cost for each facility type i and quality k. Let c_i^k be the decimal equivalents of those percentages.

e. *Supervision of construction costs*, generally computed as a lump sum, b_e, which is the total salary or salaries of one or more supervisors for the anticipated duration of the construction phase of the building; b_e is assumed constant for a given project.

f. *Cost of parking facilities per unit of area*, c_p. Support space—such as halls, elevators, toilets, and so on—is assumed to be included in the x_{ij}^k and, for this reason, its cost must be apportioned among tenants and/or buyers.

From these considerations, the following constraint inequality can be formulated:

$$(1 + c_a + c_b)\left[\sum_{k=1}^{L}\sum_{i=1}^{m}(1 + c_i^k)\left(\sum_{j=1}^{n}\beta_{ij}^k c_{ij}^k x_{ij}^k\right)\right]$$
$$+ c_p a\left[\sum_{l=1}^{m}\frac{n_l}{a_l}\left(\sum_{k=1}^{L}\sum_{j=1}^{n}x_{ij}^k\right)\right] + b_s + b_c \leq B. \qquad (6.11)$$

The constraint given above presupposes that the total number of floors, n, is known in advance. On this basis, the β_{ij}^k multipliers are obtained without difficulty. In performing an optimization study, however, design constraints would be relaxed at some point, and the total number of floors would become one of th nknown parameters. This, in turn, makes the β_{ij}^k be undetermined and a n iear, recycle loop could be generated. The following algorithm is proposed to avoid this complication:

STEP 1:

Assume that the maximum number of floors γ_r will be built (see Figure 6.2). Therefore, $n = \gamma_r$ and the corresponding β_{ij}^k multipliers are used in inequality (6.11) and in the formulation of the mathematical model. A solution is then obtained using a linear programming algorithm.

STEP 2:

Suppose that the solution generated under these conditions yields $n = \gamma_{s1}$, and that $\gamma_r \geq \gamma_{s1} \geq \gamma_{r-1}$. Then the β_{ij}^k used were the correct ones and this is an optimal solution for the constraints imposed.

If, on the other hand, $\gamma_{s1} < \gamma_{r-1}$, the β_{ij}^k used are incorrect and the solution is *not* consistent with its associated construction costs. Proceed to step 3.

STEP 3:

Now, assume that the total number of floors is $n = \gamma_{r-1} - 1$, that is, the maximum value on the next lower interval. Use this value of n to select the β_{ij}^k, formulate the model, and solve, using linear programming. Two possible results follow:

a. The solution yields $n = \gamma_{s2}$ and $\gamma_{s2} < \gamma_{r-2}$. In this case, repeat step 3 for the next lower interval.

b. The solution yields $n = \gamma_{s2}$ where $\gamma_{r-1} > \gamma_{s2} \geq \gamma_{r-2}$. Then the optimal solution for the model has been obtained and $n = \gamma_{s2}$.

5. Many other constraints can be imposed upon the objective function to make the problem conform to reality. In writing the constraints, however, one must keep in mind that they must be linear, if the problem solution is to be obtained with a linear programming algorithm, and one must be careful not to write linearly dependent and/or redundant constraints, for they can be a source of error and inefficiency in carrying out the solution.

6.1.3 Optimization Procedure

The model developed in the previous section is linear: a linear objective function is subjected to linear constraint inequalities and equations. It fits within the framework of problems which can be optimized with "linear programming" methods.

After the introduction of slack and artificial slack variables, the matrix of the structural coefficients must have the same rank as the matrix formed by augmenting the previous matrix with the column vector of stipulations for the system to have basic solutions. This is a good check on the constraint equations and should be performed before embarking upon the task of solving the problem.

6.1.4 Conclusions

The architectural planning model presented in this chapter allows the designer to make rational decisions based on the information provided by the optimal solutions generated. It must be emphasized that this approach reinforces the importance of the role played by the architect-planner in shaping the urban environment. Even with a systematic method such as the one described, he must at all times be deeply involved in the formulation of the model, especially at the "design constraint" level, for the linear model presented is a full-fledged "simulation machine," sensitive to the settings the designer gives it and responsive to the reactions of the system's economic health. A simple but descriptive numerical example problem is given in the next section.

6.1.5 Numerical Example

6.1.5.1 Statement of the Problem

An individual wishes to develop a 250 ft. × 400 ft. commercial piece of property located at the intersection of two major traffic arteries.

6.1.5.1.1. Market studies indicate that, for a development to be rentable, available office space must not exceed 2 floors, stores must not exceed 1 floor, and living units 3 floors for a "walkup" facility.

6.1.5.1.2. The studies further indicate that, within the sector of the city where the property is located, offices have a 20% vacancy rate, stores a 5% vacancy rate, and apartment units a 10% vacancy rate (occupancies must not be less than 70% to obtain financial support from a funding agency).

6.1.5.1.3. Data on market rental preferences reveal that facility areas of individual types and qualities should not exceed the following percentages of total building area:

TABLE 6–1. Rentability.

Type	*Quality*	*% of Total Building Area*
1. Offices	1	10
	2	40
	3	25
2. Stores	1	30
3. Apartments	1	40
	2	30

6.1.5.1.4. Zoning regulations for off-street parking are:
a. Offices—1 parking space/ea. 200 sq. ft. of bldg. area.
b. Stores—1 parking space/ea. 1,000 sq. ft. of bldg. area.
c. Apartments—1 parking space/ea. 800 sq. ft. of bldg. area.

Further—building coverage shall not exceed 30% of total lot area. Allow 400 sq. ft./car for parking space, drives, and so on, and a total of 5,000 sq. ft. for landscaping.

6.1.5.1.5.

TABLE 6–2. Rent ($/sq. ft./yr.)

Type	*Level*	*Quality*		
		1	*2*	*3*
1. Offices	1. Ground floor	4.50	4.00	3.50
	2. Second floor	4.00	3.50	3.00
2. Stores	1. Ground floor	3.00	—	—
3. Apartments	1. Ground floor	3.00	2.50	—
	2. Second floor	3.00	2.50	—
	3. Third floor	2.50	2.00	—

6.1.5.1.6. The $(\beta_{ij}^{k} c_{ij}^{k})$ coefficients are given below in tabular form:

TABLE 6–3. Construction Costs, Including Support Space.

Type	*Quality*	*Total Number of Floors in Building*								
		1			*2*			*3*		
		Level			*Level*			*Level*		
		Ground floor	—	—	Ground floor	Second floor	—	Ground floor	Second floor	Third floor
1. Offices	1	20.00	—	—	20.00	19.00	—	19.00	18.00	—
	2	18.00	—	—	17.00	16.00	—	17.00	15.00	—
	3	15.00	—	—	14.00	14.00	—	13.00	13.00	—
2. Stores	1	13.00	—	—	12.00	—	—	11.00	—	—
3. Apartments	1	20.00	—	—	19.00	18.00	—	18.00	17.00	17.00
	2	17.00	—	—	17.00	16 00	—	16.00	15.00	14.00

Cost of parking area = $0.75 per sq. ft.

6.1.5.1.7. Miscellaneous costs are:
a. Architectural-engineering fees—6% of total construction cost.
b. Contingencies—1.5% of total construction cost.

c. Movable furniture—
   (1) Offices—2% of total construction cost.
   (2) Stores—1% of total construction cost.
   (3) Apartments—4% of total construction cost.
d. Soil report—$3,000.
e. Supervision of construction—$2,000.

6.1.5.1.8. Budget: Shall not exceed $800,000, excluding cost of land.

Question: What types of units and how many square feet of each shall the investor develop to maximize the rent under present market conditions?

6.1.5.2 The Model

Let

$$i = \begin{cases} 1 \longrightarrow \text{Offices} \\ 2 \longrightarrow \text{Stores} \\ 3 \longrightarrow \text{Apartments} \end{cases}$$

$$j = \begin{cases} 1 \longrightarrow \text{Ground floor} \\ 2 \longrightarrow \text{Second floor} \\ 3 \longrightarrow \text{Third floor} \end{cases}$$

$$k = \begin{cases} 1 \longrightarrow \text{Quality 1} \\ 2 \longrightarrow \text{Quality 2} \\ 3 \longrightarrow \text{Quality 3} \end{cases}$$

Then, from 6.1.5.1.1 and 6.1.5.1.5,

$$x^k_{13} = 0, \quad k = 1, 2, 3;$$
$$x^k_{21} = 0, \quad k = 2, 3;$$
$$x^k_{2j} = 0, \quad j = 2, 3, \qquad k = 1, 2, 3;$$
$$x^3_{3j} = 0, \quad j = 1, 2, 3.$$

From 6.1.5.1.2.

$$q^k_{1j} = .20 < .30, \quad j = 1, 2, 3, \quad k = 1, 2, 3. \quad \text{O.K.}$$
$$q^k_{2j} = .50 < .30, \quad j = 1, 2, 3, \quad k = 1, 2, 3. \quad \text{O.K.}$$
$$q^k_{3j} = .10 < .30, \quad j = 1, 2, 3, \quad k = 1, 2, 3. \quad \text{O.K.}$$

From 6.1.5.1.2, 6.1.5.1.5, and equation (6.1),

Objective Function:

$$\begin{aligned} \text{Max } E(R) = {} & .80(4.50x^1_{11} + 4.00x^2_{11} + 3.50x^3_{11} \\ & + 4.00x^1_{12} + 3.50x^2_{12} + 3.00x^3_{12}) + .95(3.00x^1_{21}) \\ & + .90(3.00x^1_{31} + 2.50x^2_{31} + 3.00x^1_{32} + 2.50x^2_{32} \\ & + 2.50x^1_{33} + 2.00x^2_{33}). \end{aligned} \tag{6.12}$$

Constraints:

1. The lowest *construction cost* is, from 6.1.5.1.6, $11.00 per sq. ft. Therefore, an upper bound to the total building area is 800,000/11.00 ≅ 74,000 sq. ft. Therefore,

$$\begin{aligned} & x^1_{11} + x^2_{11} + x^3_{11} + x^1_{12} + x^2_{12} + x^3_{12} + x^1_{21} + x^1_{31} \\ & + x^2_{31} + x^1_{32} + x^2_{32} + x^1_{33} + x^2_{33} \leq 74{,}000. \end{aligned}$$

When slack variable x_1 is introduced, obtain

$$\begin{aligned} & x^1_{11} + x^2_{11} + x^3_{11} + x^1_{12} + x^2_{12} + x^3_{12} + x^1_{21} + x^1_{31} + x^2_{31} + x^1_{32} \\ & + x^2_{32} + x^1_{33} + x^2_{33} + x_1 = 74{,}000. \end{aligned} \tag{6.13}$$

Notice that the total building area is $74{,}000 - x_1$.

2. *Market preferences.* From 6.1.5.1.3, and introducing slack variables x_2 through x_7, obtain

$$x^1_{11} + x^1_{12} + .10x_1 + x_2 = 7{,}400, \tag{6.14}$$
$$x^2_{11} + x^2_{12} + .40x_1 + x_3 = 29{,}600, \tag{6.15}$$
$$x^3_{11} + x^3_{12} + .25x_1 + x_4 = 18{,}500, \tag{6.16}$$
$$x^1_{21} + .30x_1 + x_5 = 22{,}200, \tag{6.17}$$
$$x^1_{31} + x^1_{32} + x^1_{33} + .40x_1 + x_6 = 29{,}600, \tag{6.18}$$
$$x^2_{31} + x^2_{32} + x^2_{33} + .30x_1 + x_7 = 22{,}200. \tag{6.19}$$

3. *Site building area.* From 6.1.5.1.4, in equation (6.5), and with slack variable x_8,

$$x^1_{11} + x^2_{11} + x^3_{11} + x^1_{21} + x^1_{31} + x^2_{31} + x_8 = 30{,}000. \tag{6.20}$$

4. *Parking.* From 6.1.5.1.4, in equation (6.6), and introducing slack variable x_9, form

$$\begin{aligned} & 3.00(x^1_{11} + x^2_{11} + x^3_{11}) + 2.00(x^1_{12} + x^2_{12} + x^3_{12}) \\ & + 1.40x^1_{21} + 1.50(x^1_{31} + x^2_{31}) + .50(x^1_{32} + x^2_{32} + x^1_{33} + x^2_{33}) \\ & + x_9 = 95{,}000. \end{aligned} \tag{6.21}$$

5. *Design decisions* (massing study). (All floors must be approximately the same size.) First floor area approximately equal to second floor area:

$$\begin{aligned} x^1_{11} + x^2_{11} + x^3_{11} + x^1_{21} + x^1_{31} + x^2_{31} = {} & x^1_{12} + x^2_{12} + x^3_{12} \\ & + x^1_{32} + x^2_{32} + e_1. \end{aligned}$$

First floor area approximately equal to third floor area:

$$x^1_{11} + x^2_{11} + x^3_{11} + x^1_{21} + x^1_{31} + x^2_{31} = x^1_{33} + x^2_{33} + e_2.$$

Let $e_1 = e_2 = 1{,}000$ to avert degeneracy. This means the second and third floor areas will be within 1,000 sq. ft. of the first floor area.

One can write:

$$x^1_{11} + x^2_{11} + x^3_{11} + x^1_{21} + x^1_{31} + x^2_{31} - (x^1_{12} + x^2_{12} + x^3_{12} + x^1_{32} + x^2_{32}) = 1{,}000, \qquad (6.22)$$

and

$$x^1_{11} + x^2_{11} + x^3_{11} + x^1_{21} + x^1_{31} + x^2_{31} - (x^1_{33} + x^2_{33}) = 1{,}000. \qquad (6.23)$$

Artificial slack variables must be introduced into equation's (6.22) and (6.23) before proceeding to optimize.

6. *Budget*. Under the assumption that the total number of floors in the building will be three, the budget constraint, from 6.1.5.1.6, 6.1.5.1.7, 6.1.5.1.8, in equation (6.11) and introducing slack variable x_{10}, can be written as follows:

$$\begin{aligned}&1.075[1.02(19x^1_{11} + 17x^2_{11} + 13x^3_{11} + 18x^1_{12} + 15x^2_{12} + 13x^3_{12})\\ &+ 1.01(11x^1_{21}) + 1.04(18x^1_{31} + 16x^2_{31} + 17x^1_{32} + 15x^2_{32} + 17x^1_{33}\\ &+ 14x^2_{33})] + .75[2.00(x^1_{11} + x^2_{11} + x^3_{11} + x^1_{12} + x^2_{12} + x^3_{12})\\ &+ .40(x^1_{21}) + .50(x^1_{31} + x^2_{31} + x^1_{32} + x^2_{32} + x^1_{33} + x^2_{33})] + x_{10}\\ &= 795{,}000. \qquad (6.24)\end{aligned}$$

The model is complete and a linear programming maximization of objective function (6.12) subjected to constraint equations (6.13) through (6.24) can now be performed. Because there are only 12 constraint equations, any basic feasible solution, including the optimal one, cannot contain more than 12 nonzero variables. This limitation could be removed by introducing additional constraint conditions.

In accordance with the budget algorithm given in the example, if design decision constraints are removed and the optimal solution shows that

$$x^1_{33} = x^2_{33} = 0, \qquad (6.25)$$

the total number of floors could not exceed two. Therefore, set $x^1_{33} = x^2_{33} = 0$ in the model and formulate the budget constraint equation as follows:

$$\begin{aligned}&1.075[1.02(20x^1_{11} + 17x^2_{11} + 14x^3_{11} + 19x^1_{12} + 16x^2_{12} + 14x^3_{12})\\ &+ 1.01(12x^1_{21}) + 1.04(19x^1_{31} + 17x^2_{31} + 18x^1_{32} + 16x^2_{32})]\\ &+ .75[2.00(x^1_{11} + x^2_{11} + x^3_{11} + x^1_{12} + x^2_{12} + x^3_{12}) + .40(x^1_{21})\\ &+ .50(x^1_{31} + x^2_{31} + x^1_{32} + x^2_{32})] + x_{10} = 795{,}000. \qquad (6.26)\end{aligned}$$

In a similar manner, if the new optimal solution shows

$$x^1_{12} = x^2_{12} = x^3_{12} = x^1_{32} = x^2_{32} = 0, \qquad (6.27)$$

the building can have only one floor. Hence, set $x^1_{12} = x^2_{12} = x^3_{12} = x_{32} = x^2_{32} = 0$ in the model and the budget constraint becomes

$$\begin{aligned}&1.075[1.02(20x^1_{11} + 18x^2_{11} + 15x^3_{11}) + 1.01(13x^1_{21})\\ &+ 1.04(20x^1_{31} + 17x^2_{31})]\\ &+ .75[2.00(x^1_{11} + x^2_{11} + x^3_{11}) + .40(x^1_{21})\\ &+ .50\,(x^1_{31} + x^2_{31})] + x_{10} = 795{,}000. \qquad (6.28)\end{aligned}$$

The budget algorithm describes the procedure to follow in handling cost coefficient multipliers.

When design constraints are relaxed, the *global optimal solution* is obtained.

6.1.5.3 Solution

The first run, *with no design constraints*, yielded the following data:
At a gross expected profit of $140,570 per annum, build

12,536 sq. ft. of quality 3, ground floor *offices*
16,700 sq. ft. of quality 2, second floor *offices*
15,043 sq. ft. of quality 1, ground floor *stores*
5,865 sq. ft. of quality 1, second floor *apartments*

This two-level solution was obtained using construction costs for a three-level complex. Therefore, it is necessary to change the cost coefficients in the budget constraint. The third-level variables were assigned large, positive cost coefficients in order to drive them out of solution.

The second run, *with no design constraints*, yielded the following data:
At a gross expected profit of $132,640 per annum, build

4,348 sq. ft. of quality 2, ground floor *offices*
11,660 sq. ft. of quality 3, ground floor *offices*
12,711 sq. ft. of quality 2, second floor *offices*
13,992 sq. ft. of quality 1, ground floor *stores*
3,929 sq. ft. of quality 1, second floor *apartments*

This two-level configuration constitutes the global optimal solution with which all other optima (subject to all design constraints) must be compared.

It is important to note that the global optimal solution established a building area of 30,000 sq. ft. on the ground floor and 16,640 sq. ft. on the second floor.

The third run, for which a design constraint was introduced into the model (that the ground floor area must be approximately equal to that of the second floor), yielded the following space allocation:

For a gross expected profit of $132,126 per annum, build

9,856 sq. ft. of quality 3, ground floor *offices*
2,506 sq. ft. of quality 1, second floor *offices*
18,712 sq. ft. of quality 2, second floor *offices*
1,671 sq. ft. of quality 3, second floor *offices*
14,035 sq. ft. of quality 1, ground floor *stores*

Due to *one* decision, the designer is forced to relinquish approximately $600 per annum in profit and to reallocate spaces so that a local optimum may be achieved subject to the constraint imposed upon the building configuration. Notice that the solution is not sensitive to the design constraint imposed, for the annual profit decreases only $514 in $132,640; however, the allocation of space (type and quality as well as floor level) is extremely sensitive, as can be verified by analyzing the last two solutions. Various other design decisions can be incorporated with equal ease.

6.2 OPTIMALITY IN INDUSTRIAL PARK DEVELOPMENT

6.2.1 Introduction

This example shows an application of the systems approach to decision making at the highest level of performance: the planning level. It concentrates on the use of linear programming in the planning of an industrial facility; and, although the problem is specific, it is hoped that the thinking and methodology employed in arriving at the formulation of the mathematical model, leading to the establishment of the optimum strategy, will be sufficiently clear to permit the reader to extend his own thinking into other problems where a linearization of the parameters is equally valid.

Institutional factors have purposely been left out for clarity's sake and no attempt has been made to show the economic venture analysis that must accompany such a study for, once the optimum allocation policy is known, a rate of return or other similarly well-known engineering economy analysis must be performed to ascertain the economic feasibility of the project. This evaluation has to be carried out for the before and after tax situations, where such factors as depreciation and retirement and replacement policies are given careful consideration.

Once the project has been declared profitable, the optimal location of the facility within the site must be investigated. Pattern search is the procedure recommended for this final step in what may be termed the "Optimal Site Development."

The list of references at the end of the chapter gives a publication by the author that describes the application of pattern search for the optimum location of plant facilities (see also chapter 10).

6.2.2 Statement of the Problem

The government of a small city proposes to increase its revenue by developing a 300-acre tract of land for an industrial park. Tentative agreements have been signed with five industries and the city has made commitments to finance, build, and lease on a long-term basis the plant buildings and facilities required by the industries contacted.

The city government now owns all utilities and recently completed an expansion of these facilities to allow for limited increase in demand. The maximum amount of financing available is $6,000,000.

A study of the manpower situation in the area reveals that the available local transient and out-of-town labor force will not exceed the figures given in Table 6–4.

TABLE 6–4. Labor Force.

Type	Max. Number	Annualized Average Income
1. Common Labor	400	$ 5,000
2. Semiskilled Labor	180	$ 7,000
3. Skilled Labor	100	$12,000
4. Clerical Workers	150	$ 5,000
5. Technical Personnel	120	$14,000
6. Managers	33	$30,000

The study also revealed the pattern of local spending of net disposable income, after state and federal taxes. These data are condensed in Table 6–5

TABLE 6–5. Labor Force Spending Pattern.

Type	Average State and Federal Taxes, % of Gross Income	Annualized Net Income	Average % of Net Income Spent in City Area	Cash Flow into City Area
1. Common Labor	10%	$ 4,500	90%	$ 4,050
2. Semiskilled Labor	12%	$ 6,160	85%	$ 5,240
3. Skilled Labor	16%	$10,100	70%	$ 7,070
4. Clerical Workers	10%	$ 4,500	85%	$ 3,830
5 Technical Personnel	18%	$11,500	65%	$ 7,400
6. Managers	24%	$22,800	55%	$12,520

and their computation was based on the average family size for each income level.

It has also been estimated that city revenue from taxes on sales and property and from utilities, fuel, sanitation, and so on will average about 2.5% of the flow of disposable personal income spent in the city area. The revenue that the city will accrue from the employment of each type of worker is summarized in Table 6–6.

TABLE 6–6. City Revenue from Labor Force.

Type	*Annualized Average City Revenue per Worker*
1. Common Labor	$101
2. Semiskilled Labor	$131
3. Skilled Labor	$177
4. Clerical Workers	$ 96
5. Technical Personnel	$187
6. Managers	$313

The city-owned utilities, sewerage, and waste disposal systems can satisfactorily handle the following additional loads:

1. Electricity, 14.5 × 10^6 kw. hrs./yr.
2. Water, 75.0 million gals./yr.
3. Gas, 40.0 × [illegible] cu. ft./yr.
4. Sewerage, 40.0 million gals./yr.
5. Waste Disposal, 20.0 × 10^3 tons/yr.

The city's unit profits from the sale of utilities and other services to industrial customers are:

1. Electricity, $0.0007 per kw. hr.
2. Water, $7.00 per million gals.
3. Gas, $0.004 per cu. ft.
4. Sewerage, $1.00 per million gals.
5. Waste, $0.15 per ton.

The five potential customer industries with which the city government has signed tentative agreements will use most of the area's raw materials. Even though this and many other industry-derived benefits will upgrade the community's income level, they cannot be quantified accurately and for this reason will be disregarded in the optimization strategy. Nevertheless, they must be recognized as a plus factor in the decision to implement the plan.

Table 6–7 gives information on the maximum and minimum plant building area requirements for each industry.

Tables 6–8 through 6–10 summarize resource requirements and production levels for each 1,000 square feet of plant building area, for each of the five industries considered.

The city government will impose a 1.5% tax on the gross annual production value of each industry.

The site costs to the city in the location selected for the industrial park will be $2,000 per acre, and the average building construction costs for the various plants are summarized below:

Industry 1 (Electronics)—$15/sq. ft.
Industry 2 (Pressure Vessels)—$17/sq. ft.
Industry 3 (Metal Castings)—$19/sq. ft.
Industry 4 (Plastic Laminates)—$22/sq. ft.
Industry 5 (Recapped Tires)—$16/sq. ft.

The city has agreed to lease the building facilities (including grounds) at an annual cost to the industries of $1.75/sq. ft. of building area. Maintenance costs have been estimated at $0.05/sq. ft. of building area per year.

The city government desires to establish the optimum allocation of space to each industry—that is, the allocation that, consistent with the constraints, will produce the highest annual revenue to the local government.

6.2.3 Mathematical Model

6.2.3.1 The Objective Function

Let x_i, $i = 1, \dots, 5$, be the plant building areas, in 1,000 sq. ft., to be leased to industries 1 through 5, respectively.

The total annual income the city government can expect to receive as a result of its investment in the industrial park can be broken down as follows:

1. Revenue from labor force spending habits: Table 6–6.
2. Income from utility and other service charges.
3. Revenue from tax on industrial production: Table 6–10.
4. Income from plant building leases minus maintenance costs.

TABLE 6–7. Plant Building Area Requirements.

Industry	*Principal Product*	*Max. Bldg. Area sq. ft.*	*Min. Bldg. Area sq. ft.*
1	Electronics	120,000	40,000
2	Pressure Vessels	80,000	20,000
3	Metal Castings	70,000	26,000
4	Plastic Laminates	100,000	28,000
5	Recapped Tires	150,000	35,000

TABLE 6–8. Labor Force Requirements in Men/Day (8-hour shifts) per 1,000 sq. ft. of Plant Building Area.

Industry	*Principal Product*	*Common*	*Semi-skilled*	*Skilled*	*Clerical*	*Technical*	*Man-agerial*
1	Electronics	0.75	0.23	0.38	0.30	0.15	0.05
2	Pressure Vessels	0.90	1.35	0.30	0.60	0.30	0.15
3	Metal Castings	1.30	0.46	0.46	0.58	0.23	0.15
4	Plastic Laminates	0.43	0.64	0.32	0.75	0.32	0.07
5	Recapped Tires	1.37	0.34	0.17	0.17	0.69	0.11

Let $j = 1, \ldots, 6$ be indices representing common, semiskilled, skilled, clerical, technical, and managerial personnel; r_j, $j = 1, \ldots, 6$ be the city revenue from the labor force local spending habits (Table 6–6); L_{ij}, $i = 1, \ldots, 5$, $j = 1, \ldots, 6$ be the number of workmen employed by industry i of type j per 1,000 sq. ft. of plant building area (Table 6–7); and p_i, $i = 1, \ldots, 5$ be the annual production for industry i in dollars per 1,000 sq. ft. of plant building area (Table 6–10).

Also let $k = 1, \ldots, 5$ be indices representing electric, water, gas, sewerage, and waste disposal services; C_k, $k = 1, \ldots, 5$ be the unit profits from electric, water, gas, sewerage, and waste disposal services; and u_{ik}, $i = 1, \ldots, 5$, $k = 1, \ldots, 5$ be the requirements of industry i for electric, water, gas, sewerage, and waste disposal services (Table 6–9).

Adhering to these definitions, the objective function can now be written:

$$\text{Max } I = \sum_{i=1}^{5} \left[\sum_{j=1}^{6} L_{ij} r_j + \sum_{k=1}^{5} C_k u_{ik} + 0.015 p_i + 1{,}700 \right] x_i \qquad (6.29)$$

6.2.3.2 The Constraints

The region of feasibility is defined by the following set of constraints.

1. Initial capital investment on land and buildings cannot exceed \$6,000,000.
2. Maximum available labor force cannot be exceeded: Table 6–4.
3. Maximum utility and service levels cannot be exceeded.
4. Maximum amount of land available is 300 acres: area of industrial park.
5. Maximum and minimum plant building areas must be maintained: Table 6–7.

Let E_j, $j = 1, \ldots, 6$ be the maximum available number of type j workers (Table 6–4); A_i and a_i, $i = 1, \ldots, 5$ be, respectively, the maximum and minimum plant area requirements in 1,000 sq. ft. (Table 6–7); b_i, $i = 1, \ldots, 5$ be the unit building costs in dollars per sq. ft. for plant type i; s_i, $i = 1,$ $\ldots$ be the amount of land required for industry i, in acres per 1,000 sq. f

TABLE 6–9. Site and Services Requirements in Units per 1,000 sq. ft. of Plant Building Area.

Industry	*Principal Product*	*Site* (acres/ *1,000 ft.²*)	*Electricity* (kw. hrs./yr./ *1,000 ft².*)	*Water* (million gals./ *yr./1,000 ft.²*)	*Gas* (cu. ft./yr./ *1,000 ft.²*)	*Sewerage* (million gals./ *yr./1,000 ft.²*)	*Waste* (tons/yr./ *1,000 ft.²*)
1	Electronics	0.50	40,000	0.050	60,000	0.040	20
2	Pressure Vessels	1.00	32,000	0.100	80,000	0.058	30
3	Metal Castings	1.15	62,000	0.300	120,000	0.200	50
4	Plastic Laminates	1.43	48,000	0.200	75,000	0.150	45
5	Recapped Tires	1.43	58,000	0.100	150,000	0.060	25

TABLE 6–10. Annualized Industrial Production in \$/yr. per 1,000 sq. ft. of Plant Building Area.

Industry	*Principal Product*	*Annualized Value Added (\$/1,000 ft.²)*
1	Electronics	5,000
2	Pressure Vessels	7,000
3	Metal Castings	12,000
4	Plastic Laminates	15,000
5	Recapped Tires	10,000

of plant building area (Table 6-9); and let $U_k, k = 1, \dots, 5$ be the maximum available levels of electric, water, gas, sewerage, and waste disposal services.

Then the constraints can be written:

1. Capital Investment

$$1{,}000 \sum_{i=1}^{5} b_i x_i \leq 5{,}400{,}000. \tag{6.30}$$

2. Labor Force

$$\sum_{i=1}^{5} L_{ij} x_i \leq E_j; j = 1, \dots, 6 \tag{6.31}$$

3. Utility and Service Levels

$$\sum_{i=1}^{5} u_{ik} x_i \leq U_k; k = 1, \dots, 5 \tag{6.32}$$

4. Available Acreage

$$\sum_{i=1}^{5} s_i x_i \leq 300 \tag{6.33}$$

5. Plant Building Areas

$$a_i \leq x_i \leq A_i; i = 1, \dots, 5 \tag{6.34}$$

This completes the mathematical description of the model.

The substitution of numerical values into the model and the introduction of slack variables yield the following system.

Objective Function:

$$\text{Max } I = 2{,}292.03x_1 + 2{,}634.16x_2 + 2{,}831.82x_3 + 2{,}604.56x_4 + 2{,}887.89x_5 \tag{6.35}$$

Constraints:

1. Investment

$$15{,}000x_1 + 17{,}000x_2 + 19{,}000x_3 + 22{,}000x_4 + 16{,}000x_5 + x_6 = 5{,}400{,}000 \tag{6.36}$$

2. Labor Force

a. Common

$$0.75x_1 + 0.90x_2 + 1.30x_3 + 0.43x_4 + 1.36x_5 + x_7 = 400 \tag{6.37}$$

b. Semiskilled

$$0.23x_1 + 1.35x_2 + 0.46x_3 + 0.64x_4 + 0.34x_5 + x_8 = 180 \tag{6.38}$$

c. Skilled

$$0.38x_1 + 0.30x_2 + 0.46x_3 + 0.32x_4 + 0.17x_5 + x_9 = 100 \tag{6.39}$$

d. Clerical

$$0.30x_1 + 0.60x_2 + 0.58x_3 + 0.75x_4 + 0.17x_5 + x_{10} = 150 \tag{6.40}$$

e. Technical

$$0.15x_1 + 0.30x_2 + 0.23x_3 + 0.32x_4 + 0.69x_5 + x_{11} = 120 \tag{6.41}$$

f. Managerial

$$0.05x_1 + 0.15x_2 + 0.15x_3 + 0.07x_4 + 0.11x_5 + x_{12} = 33 \tag{6.42}$$

3. Utility and Service Levels

a. Electricity

$$40{,}000x_1 + 32{,}000x_2 + 62{,}000x_3 + 48{,}000x_4 + 58{,}000x_5 + x_{13} = 14.5x10^{6} \tag{6.43}$$

b. Water

$$0.050x_1 + 0.100x_2 + 0.300x_3 + 0.200x_4 + 0.100x_5 + x_{14} = 75.0 \tag{6.44}$$

c. Gas

$$60{,}000x_1 + 80{,}000x_2 + 120{,}000x_3 + 75{,}000x_4 + 150{,}000x_5 + x_{15} = 40.0x10^{6} \tag{6.45}$$

d. Sewerage

$$0.040x_1 + 0.058x_2 + 0.200x_3 + 0.150x_4 + 0.60x_5 + x_{16} = 40.0 \tag{6.46}$$

e. Waste

$$20x_1 + 30x_2 + 50x_3 + 45x_4 + 25x_5 + x_{17} = 20.0x10^{3} \tag{6.47}$$

4. Acreage

$$0.50x_1 + 1.00x_2 + 1.15x_3 + 1.43x_4 + 1.43x_5 + x_{18} = 300 \qquad (6.48)$$

5. Plant Building Areas
   a. Maximum Areas

$$x_1 + x_{19} = 120 \qquad (6.49)$$
$$x_2 + x_{20} = 80 \qquad (6.50)$$
$$x_3 + x_{21} = 70 \qquad (6.51)$$
$$x_4 + x_{22} = 100 \qquad (6.52)$$
$$x_5 + x_{23} = 150 \qquad (6.53)$$

   b. Minimum Areas

$$x_1 - x_{23} = 40 \qquad (6.54)$$
$$x_2 - x_{24} = 20 \qquad (6.55)$$
$$x_3 - x_{25} = 26 \qquad (6.56)$$
$$x_4 - x_{26} = 28 \qquad (6.57)$$
$$x_5 - x_{27} = 35 \qquad (6.58)$$

6.2.4 Solution

The solution, obtained with a standard linear programming package, yielded the following results:

1. *Maximum Annual Income* = $810,046
2. *Initial Investment* = $5,238,314
3. *Optimum Plant Building Areas*
   Industry 1 (Electronics)—120,000 sq. ft.
   Industry 2 (Pressure Vessels)—73,228 sq. ft.
   Industry 3 (Metal Castings)—26,000 sq. ft.
   Industry 4 (Plastic Laminates)—28,000 sq. ft.
   Industry 5 (Recapped Tires)—67,714 sq. ft.
4. *Optimum Land Area* = 300 acres
5. *Labor Utilization*
   Common—294
   Semiskilled—179
   Skilled—100
   Clerical—127
   Technical—102
   Managerial—30
6. *Utility and Service Levels*
   Electricity—14,026,743 kw. hr./yr.
   Water—33.49 million gals./yr.
   Gas—28,435,428 cu. ft./yr.
   Sewerage—22.51 million gals./yr.
   Waste—8,850 tons/yr.

All-solution values are feasible; they do not violate any of the limitations imposed upon the resources.

6.2.5 Conclusions and Observations

In building mathematical models for real life problems, one must be careful to verify that the available number of resources is sufficient to fulfill their minimum levels of utilization, for otherwise there will *not* exist any feasible alternatives to implement the plan.

It must also be pointed out that the industries used in the example as well as the data presented, although realistic, are strictly hypothetical. The principal concern here has been to guide the reader through a modeling situation and to stress the need to use the systems approach to planning in optimizing real problems even when they exhibit only a moderate level of complexity.

EXERCISES

6–1. The southern California area is faced with the problem of ultimately supplying water to a future population of 40 million people. Assuming that the future water demand will be 190 gal./day/capita, the water required by the area will be 7,600 m.g.d. Local surface water and ground water can supply only 990 m.g.d. Other possible sources of water are as follows:

1. An aqueduct system to the Colorado River and to the Feather River located at a distance of some 200 miles, with a total capacity of 4,000 m.g.d.
2. Reclaimed waste water from domestic sewerage treatment with a maximum of 3,200 m.g.d.
3. Desalinized water from the ocean, which can be supplied in unlimited quantities by the electrolytic ion-exchange method.

The quality of the water to be supplied must contain no more than 700 p.p.m total dissolved solids; no more than 250 p.p.m sulfates; and no more than 110 p.p.m chlorides.

Data on the possible sources are given below:

	Colorado River	*Feather River*	*Reclaimed Waste*	*Desalinized Water*	*Local Source*
Cost ($/1,000 gal.)	0.21	0.70	0.50	0.80	0.15
T.D.S. (p.p.m.)	805.	720.	634.	500.	650.
Sulfates (p.p.m.)	335.	132.	366.	30.	150.
Chlorides (p.p.m.)	118.	137.	20.	30.	60.

The problem is to adequately supply the water required at a minimum cost.

6–2. Develop planning problems utilizing the models described in this chapter. Introduce variations and try to expand the model formulations to fit other physical situations.

6–3. A lamp manufacturer is investigating the possibility of expanding his plant. For expansion to be feasible, the additional facility must (1) have a minimum capacity to produce 300 lamps per month; and (2) produce a minimum profit of $1,500 per month from a maximum budget of $5,000 per month.

The lamp manufacturer produces four types of lamps: (1) ceramic lamps, (2) pine lamps, (3) oak lamps, and (4) mahogany lamps. The unit cost to produce the lamps is $3, $5, $10, and $15, respectively. The manufacturer's unit profit is $1, $2, $3, and $5, respectively. The resources available constrain the monthly production to no more than 130 ceramic lamps, 400 pine lamps, 240 oak lamps, and 130 mahogany lamps. The availability of skilled lathe operators limits the production of wooden lamps to 630 per month.

Based on a market survey, the maximum demand for additional lamps is 750 per month with the following breakdown: 20% ceramic, 40% oak, 25% pine, and 15% mahogany lamps, respectively. Determine whether or not it is feasible to expand the plant.

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ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

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2. CONCEPTOS Y TECNICAS MODERNAS DE ANALISIS, DISEÑO Y DIRECCION DE SISTEMAS DE OPERACION DECISIONAL.

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CONCEPTOS Y TECNICAS MODERNAS DE ANALISIS, DISEÑO Y DIRECCION DE SISTEMAS DE OPERACION DECISIONAL Y NECESIDAD DE SU UTILIZACION EN INGENIERIA CIVIL

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1. INTRODUCCION

En este trabajo se presentan muy someramente algunos conceptos y técnicas para el análisis, diseño y dirección de sistemas de operación decisional, que se han precisado y desarrollado en los últimos 15 años. Estas técnicas han producido en los Estados Unidos una verdadera revolución en la dirección de empresas industriales, y han permitido realizar eficientemente proyectos gigantescos, por su magnitud y complejidad.

El propósito del presente trabajo es hacer notar la necesidad de utilizar en Ingeniería Civil las técnicas presentadas. El autor estima que la aplicación de dichas técnicas en la Ingeniería Civil mexicana es indispensable para responder a las demandas que a ella le impone el creciente desarrollo económico de México.

2. CONCEPTOS BASICOS

2.1. *Sistema*

Un sistema es un conjunto cuyos elementos están relacionados entre ellos de manera que la operación de uno de sus elementos *afecta* la operación de *todos* los demás. Los sistemas pueden ser de dos tipos: *a*) Sistemas de operación fija y *b*) Sistemas de operación decisional. En los sistemas de operación fija la operación debe hacerse siguiendo reglas predeterminadas por el diseñador, por ejemplo, un teléfono, un automóvil, etc. En los sistemas de operación decisional la operación, y consecuentemente el resultado de la operación del sistema, puede ser decidida por el personal que opera el sistema, por ejemplo, un sistema hidroeléctrico, un sistema de transportes (aéreos, marítimos, terrestres, eléctricos), etc.

2.2. *Sistema organizado de operación decisional*

La motivación básica, consciente o subconsciente, de la creación o la existencia de una empresa, es la consecución de ciertos objetivos de manera que alguna medida de la eficiencia (utilidades, costo, volumen de producción, etc.) resulte óptima. Los empresarios, preocupados fundamentalmente por alcanzar los objetivos en cuestión, con frecuencia han descuidado factores de organización que les han provocado pérdidas cuantiosas, tanto económicas como de tiempo. La necesidad de reducir o eliminar estas pérdidas ha impulsado la investigación de métodos científicos de análisis, diseño, operación y dirección de empresas. El punto de estos métodos es que una empresa sólo puede alcanzar sus objetivos con máxima eficiencia si se la considera como un sistema de operación decisional que tiene las siguientes características:

a) *Objetivos coordinados*: es decir, objetivos de las componentes del sistema compatibles con los objetivos del sistema y con los recursos disponibles en éste.

b) *Organización acorde con los objetivos*: es decir, que la departamentalización funcional, la delegación de autoridad y la asignación de responsabilidad deben ser acordes con los objetivos del sistema.

c) *Contenido acorde con los objetivos*; o sea, el personal, los materiales, el equipo, el dinero y la información contenida en cada elemento del sistema sea acorde con los objetivos de éste.

d) *Operación del sistema de manera que haga posible la consecusión de los objetivos*; es decir, que los flujos de personal, materiales, equipo, dinero e información que implica la operación del sistema, deben hacer posible la consecución de los objetivos.

e) *Controles* para determinar si ocurren desviaciones en el contenido, en la organización o en la operación del sistema, que provoquen trastornos en la consecución de los objetivos, y en caso de que ocurran dichas desviaciones, poder tomar decisiones correctivas adecuadas.

3. ELEMENTOS BASICOS DEL ANALISIS DE UN SISTEMA DE OPERACION DECISIONAL

3.1. *Análisis de las funciones en un sistema*

Todo elemento de un sistema de operación decisional *produce bienes o servicios*. La naturaleza de éstos depende de la especialidad y los objetivos del sistema. Sin embargo, cualquiera que sean éstos; es decir, cualquiera que sea el campo de especialidad del sistema y sus objetivos, las funciones que realiza cualquier elemento del sistema

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pueden clasificarse en alguno de los grupos principales siguientes:

a) Investigación y desarrollo.
b) Producción.
c) Ventas.
d) Financiamiento y contraloría.
e) Funciones relativas al personal.
f) Relaciones públicas.
g) Funciones jurídicas o legales.

En una empresa industrial moderna los grupos anteriores pueden subdividirse como se muestra en los cuadros de las páginas 16-21 de la ref. 1.

3.2. *Análisis de la estructura del sistema*

En un sistema establecido de operación decisional las funciones descritas en el inciso anterior se encuentran asignadas a departamentos. Con frecuencia, un grupo o un subgrupo de funciones está asignado a uno o varios departamentos del sistema, dependiendo del grado de desarrollo y de las condiciones de operación del sistema. También, la dirección de las actividades de uno o de varios departamentos se encomienda a un jefe. Como se sabe, el diagrama que muestra la departamentalización de las funciones del sistema, y la dependencia de cada departamento en cuanto a dirección, se denomina *organigrama*.

La información principal que puede extraer el analista de sistemas de operación decisional al estudiar un organigrama es:

a) Qué grado de desarrollo tiene el sistema (el desarrollo del sistema es mayor a medida que aumenta la necesidad de crear nuevos departamentos).
b) Quien es responsable de la dirección de los diferentes grupos de actividades.
c) Ante quien es responsable cada elemento directivo del sistema.
d) Existencia de multiplicidad de mando.
e) Existencia de actividades cuya ejecución no se ha asignado a nadie específicamente.
f) Necesidad de formar nuevos departamentos.

3.3. *Análisis del contenido del sistema*

El contenido de un sistema de operación decisional lo constituyen:

a) El personal.
b) El equipo y las instalaciones.
c) Los materiales.
d) El dinero.
e) La información.

La información principal qué proporciona el análisis de cada uno de estos elementos es:

Respecto al personal: cantidad disponible, preparación y capacidad, relaciones laborales, intereses creados, servicios que se prestan al personal, etc.

Respecto al equipo y las instalaciones: cantidad y capacidad, condiciones de operación y mantenimiento, adecuacidad respecto a los objetivos, distribución en planta, etc.

Respecto a materiales: capacidad y calidad de los almacenamientos disponibles, medio de manejo de materiales, etc.

Respecto al dinero: activo fijo, activo circulante, pasivo exigible a corto plazo, pasivo exigible a largo plazo, etc.

Respecto a la información: capacidad y características de los archivos o almacenamientos de información, etc.

3.4. *Análisis de la operación del sistema*

La operación de un sistema de operación decisional implica movimiento o *flujo* de personal, materiales, equipo, dinero e información entre los diferentes elementos componentes del sistema. Es posible construir un modelo gráfico de la operación de un sistema introduciendo simbolos que representen:

a) Los elementos del sistema.
b) El proceso que se realiza en cada elemento.
c) Cada uno de los flujos (de personal, materiales, equipo, dinero e información) indicando: contenido del flujo, sentido en que ocurre y medio que lo conduce.
d) La unidad de control de cada flujo.

El modelo que resulta[2] tiene todo el aspecto de una red de distribución de corriente eléctrica o de agua potable. Geométricamente dicho modelo constituye una *gráfica*. En ocasiones, para facilitar el análisis, se representa separadamente el flujo de personal, materiales, equipo y dinero y el flujo de información asociado correspondiente.

El proceso que se realiza en cada elemento del sistema puede representarse mediante un diagrama o gráfica de flechas y analizarse utilizando el método CPM o PERT[3].

La información principal que se obtiene de los análisis precedentes es:

a) Eficiencia de la operación del sistema.
b) Localización de elementos cuya operación es defectuosa ("cuellos de botella").
c) Localización de fallas en la organización.

3.5. *Análisis de los controles en un sistema*

La operación de un sistema de operación decisional establecido depende de las decisiones que tome el personal directivo de todos los elementos del mismo. Estas decisiones afectan el contenido y los flujos de contenido en el sistema, y consecuentemente, los procesos que deben realizarse en cada uno de sus elementos. El grado de control en un intervalo de tiempo se mide por la diferencia que hay entre los objetivos *planeados* para el intervalo y los *resultados obtenidos* durante él. Si esa diferencia disminuye con el tiempo, el grado de control aumenta, y viceversa.

De acuerdo con la discusión del párrafo anterior el análisis de los controles en el sistema, deberá enfocarse a determinar para cada período conveniente de tiempo durante la vida del sistema:

a) Qué objetivos existían en los diferentes períodos de tiempo para cada elemento del sistema.

b) Qué grado de compatibilidad existía entre los objetivos de los diferentes elementos del sistema.

c) Qué diferencias se presentaron en cada período entre los objetivos planeados y los resultados obtenidos durante el período correspondiente.

d) Qué causas provocaron en cada período las desviaciones observadas entre objetivos planeados y resultados obtenidos.

Merece especial atención el estudio de las causas de las desviaciones observadas entre resultados y objetivos planeados. Estas desviaciones pueden clasificarse en dos tipos:

a) Desviaciones provocadas por defectos del sistema mismo.

b) Desviaciones provocadas por causas ajenas al sistema y atribuibles al medio que lo rodea.

Si el diseño del sistema fuese tal que las desviaciones del tipo *a*) tendiesen a desaparecer, el sistema de operación decisional tendería a un sistema de operación fija, y las decisiones que tendría que tomar el personal directivo de los diferentes elementos del sistema serían necesarias solamente "por excepción"; es decir, solamente cuando ocurrieran circunstancias *realmente* imprevistas, dentro y fuera del sistema.

La información principal que se obtiene del análisis de los controles en el sistema es:

a) Grado de control en la operación.

b) Fallas en la planeación o ausencia total de planeación.

c) Información para control insuficiente en algunos aspectos e innecesaria en otros.

d) Fallas en el diseño del sistema.

4. DISEÑO DE UN SISTEMA DE OPERACION DECISIONAL: APLICACION DE LA METODOLOGIA CIENTIFICA

4.1. *El problema de diseño de un sistema de operación-decisional*

Los objetivos de un sistema de operación decisional cambian con el tiempo. Este hecho obliga al investigador de sistemas a analizar con alguna frecuencia al sistema en cuestión con el fin de determinar si éste permite alcanzar los objetivos con la máxima eficiencia o si hay necesidad de rediseñar el sistema en alguna o algunas de sus componentes.

El problema de diseño de un sistema de operación decisional presenta las siguientes características:

a) Una persona o un grupo de personas que tiene que tomar las decisiones durante la fase de diseño del sistema hasta seleccionar un diseño para operación.

b) Una persona o un grupo de personas (usualmente distinto del grupo en *a*)) que tiene que tomar las decisiones durante la operación del sistema.

c) Posibilidad de establecer y coordinar los objetivos del sistema en varias formas alternativas.

d) Necesidad de establecer una medida de la eficiencia del sistema o de la parte del sistema que se diseña.

e) Posibilidad de varias alternativas no igualmente eficientes para alcanzar los objetivos deseados.

f) Duda respecto a la elección del diseño "óptimo".

g) Un medio ambiente que produce un efecto riesgoso o incierto sobre el sistema.

Puede observarse que excepto por el factor *b*) anterior, los otros factores intervienen en mayor o en menor grado en el diseño de sistemas de operación fija. Esto ha permitido utilizar la metodología científica para el diseño de este tipo de sistemas en el diseño de sistemas de operación decisional, y viceversa. Muy recientemente esta metodología ha sido desarrollada notablemente[4, 5].

4.2. *Insumo, producto, eficiencia. Objetivos y evaluación de objetivos*

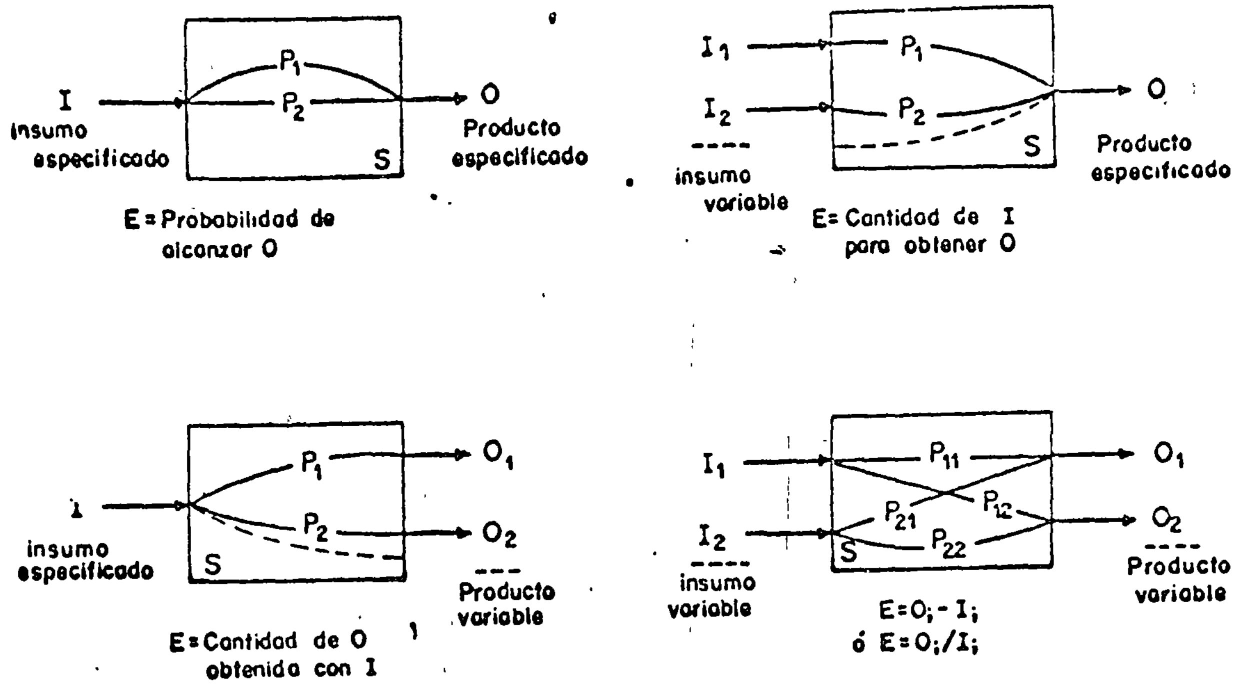
La selección de uno de los diseños alternativos posibles de procesos a realizar en un sistema de operación decisional o en una parte de él, se hace en función de lo que se denomina *eficiencia*. En la fig. 1 se muestran los cuatro casos posibles de relaciones entre producto e insumo, y la medida de eficiencia correspondiente.

Los objetivos de un sistema de operación decisional o de una parte de él, pueden referirse al insumo o al producto y pueden ser cualitativos o cuantitativos. En general, para lograr el mejor diseño del sistema o de la parte en cuestión no es suficiente con renunciar los objetivos que se pretenden, sino que hay que evaluarlos. Muy recientemente se han desarrollado técnicas de evaluación[4], de aplicabilidad general y de gran utilidad para evaluar los objetivos.

4.3. *Modelo de un sistema. Ventajas que tiene su utilización*

Como se sabe, un modelo de un sistema es una representación del sistema. Un modelo puede ser físico o abstracto.

Entre los modelos físicos los más importantes son los analógicos, es decir, aquellos cuyas magnitudes físicas representan a las magnitudes características del sistema, de manera que a cada magnitud del modelo corresponde una y sólo una magnitud del sistema. A esta clase de modelos



Notación

I insumo ó recursos que entran en el sistema
O producto ó recursos que salen procesados del sistema
P uno de los procesos o cursos de acción posibles en el sistema
E. eficiencia

FIGURA 1

corresponden los modelos gráficos y los modelos eléctricos.

Los modelos abstractos son los modelos matemáticos. En éstos, las variables que aparecen representan a magnitudes características del sistema, y el conjunto de relaciones matemáticas que deben satisfacer dichas variables para representar al sistema constituye propiamente el modelo del sistema.

Si las magnitudes características de un modelo no cambian con el tiempo, el modelo se llama estático. Si dichas magnitudes cambian con el tiempo, el modelo se llama dinámico. Un sistema cuyas magnitudes características cambian con el tiempo puede ser representado por un modelo estático en un cierto período de tiempo, si la variación de las magnitudes en cuestión es pequeña; en caso contrario, el sistema tiene que representarse por un modelo dinámico.

Es posible representar mediante un modelo a una parte del sistema o al sistema en conjunto. Por lo que se refiere a sistemas de operación fija, las técnicas de representación, análisis, diseño y optimización del diseño[6], se encuentran muy desarrolladas. Algunas de estas técnicas han sido utilizadas en sistemas de operación decisional, basándose en la similitud anotada al final del inciso 4.1 entre este tipo de sistemas y los sistemas de operación fija. Así, se ha utilizado la teoría de los servomecanismos para representar y simular la operación de sistemas de producción o distribución organizados[7]. También se han desarrollado modelos específicos para sistemas de operación decisional[7, 8]. En la actualidad este campo se encuentra en proceso de desarrollo verdaderamente explosivo.

Las ventajas principales que tiene la utilización de modelos para representar a sistemas, tanto de operación fija como de operación decisional son:

a) Es menos difícil medir las variables características en el modelo que en el sistema real.
b) Permiten encontrar relaciones entre las magnitudes características del sistema que sería imposible o muy difícil descubrir mediante análisis directos del sistema.

c) Permiten determinar el diseño óptimo (respecto a algún criterio) del sistema para condiciones de operación dadas.
d) Permiten la experimentación (simulación) en condiciones controladas, menos difíciles y menos costosas que en el sistema.
e) Proporcionan la única base posible para el desarrollo de la rama del conocimiento correspondiente.
f) Permiten la enseñanza.

La desventaja principal de los modelos de sistemas es que constituyen idealizaciones más o menos refinadas de dichos sistemas. Sin embargo, no deben olvidarse las dificultades que tiene la experimentación con el único modelo fiel de un sistema, o sea, con el sistema mismo.

4.4. *La investigación de operaciones. Algunas clases de problemas estudiados. Uso de computadoras electrónicas*

Recientemente se ha hablado mucho de las ventajas que tiene la utilización de los métodos y modelos de la Investigación de Operaciones en problemas desarrollo económico, de dirección de empresas, etc. Sin embargo, con frecuencia no se tiene un concepto claro de lo que es. La Investigación de Operaciones es una rama de las Matemáticas que se caracteriza por:

a) Estudiar sistemas de operación decisional.
b) Desarrollar modelos matemáticos o analógicos de los sistemas que estudia.
c) Desarrollar técnicas para optimizar la eficiencia de los sistemas que estudia.

La metodología que emplea la Investigación de Operaciones es la metodología científica[4 y 2].

El proceso que se sigue en Investigación de Operaciones para atacar un problema específico puede representarse gráficamente como se indica en la fig. 2.

La forma básica de los modelos de investigación de operaciones es

$$E = f(C_i, U_j)$$

en donde

E = Eficiencia del sistema.
C_i = Variables sujetas a control por decisión ($i = 1, 2, \ldots n$).
U = Variables o constantes que no están sujetas a control por decisión y que afectan la eficiencia ($j = 1, 2, \ldots n$).
$f(C_i, U_j)$ = Símbolo que indica función f de C_i, U_j.

El problema es: fijados los valores de U_j, determinar los valores correspondientes de C_i (si existen) que hacen óptima (máxima o mínima) la eficiencia E, sabiendo que las variables están sujetas a ciertas restricciones, impuestas usualmente por limitaciones en los recursos disponibles o por deseos de retener algunos factores.

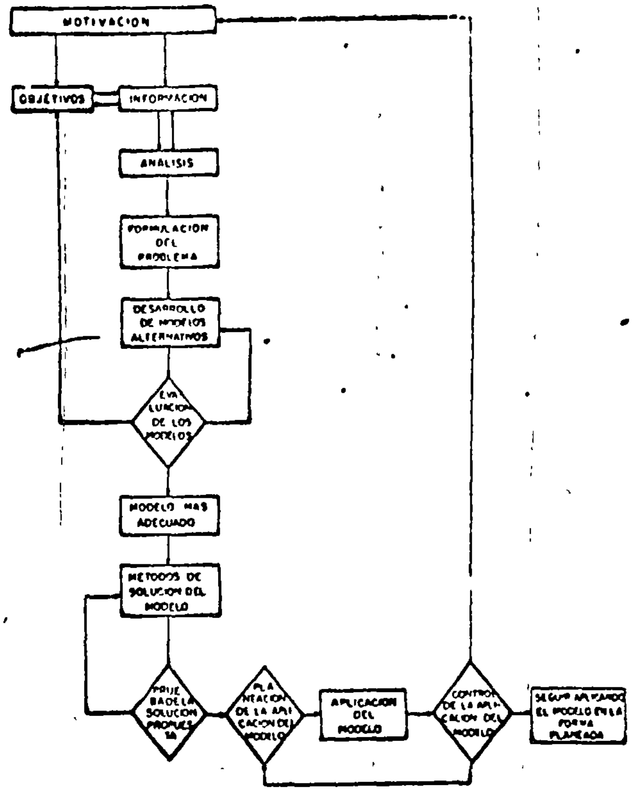


FIGURA 2

Los problemas que se han atacado en Investigación de operaciones pueden clasificarse* en problemas de:

a) Inventarios	*e)* Rutas
b) Asignación	*f)* Reemplazo
c) Espera	*g)* Competencia
d) Secuenciación*	*h)* Búsqueda

Algunas de las técnicas de la Investigación de Operaciones han sido aplicadas en: investigación y desarrollo, producción, ventas, financiamiento, dirección de personal, compras, planeación general, etc. En todas estas aplicaciones la utilización de computadoras digitales electrónicas ha sido de gran utilidad. Con frecuencia, ha sido la computadora electrónica la que ha permitido la utilización de los métodos de Investigación de Operaciones en problemas de gran magnitud y complejidad.

5. PRINCIPIOS DE DIRECCION MODERNA DE SISTEMAS DE OPERACION DECISIONAL

A pesar de que desde 1916 Fayol[10] presentó con toda claridad los principios básicos de la dirección de empresas, y de que demostró que usando esos principios es posible *enseñar* a dirigir

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* Los métodos CPM y PERT que han adquirido tanta popularidad recientemente, son métodos para problemas de esta clase.

una empresa, dichos principios permanecieron ignorados por la gran mayoría de los dirigentes de empresas en todo el mundo, hasta que hace aproximadamente 15 años se inició su difusión en gran escala. Este hecho impulsó la investigación acerca de la dirección de empresas, y, en general, acerca de la dirección de sistemas de operación decisional. Como resultado de dichas investigaciones, se dispone ahora de un conjunto de principios sólidamente fundamentados para la dirección de sistemas de operación decisional [11, 12].

Actualmente se reconoce que todas las actividades relacionadas con la *dirección* de cualquier parte de un sistema de operación decisional o del sistema en conjunto, pueden clasificarse en los cuatro grupos que se muestran en la fig. 3, y que esos grupos de actividades directivas se realizan *cíclicamente* como se indica en la figura, durante *todo el tiempo* que está en operación el sistema.

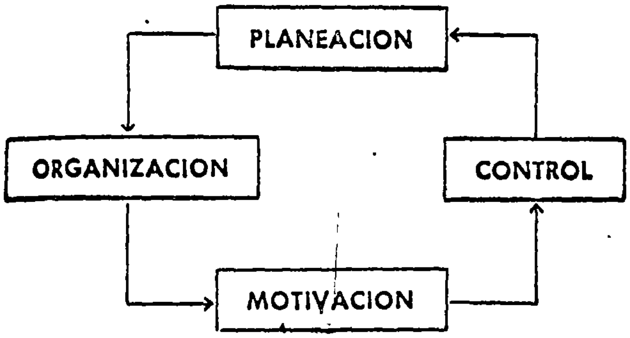

FIG. 3. *Ciclo dinámico de la dirección*

Con el fin de precisar el significado de los términos que aparecen en la fig. 3, se definen a continuación:

Planeación: conjunto de decisiones tendientes a lograr en el futuro los objetivos establecidos, en la forma más eficiente posible.

Organización: conjunto formado por los elementos del sistema a los que se asignan las actividades que deben realizarse para alcanzar los objetivos establecidos, y por el personal en quien se delega la autoridad y la responsabilidad para dirigir la operación de dichos elementos.

Motivación: conjunto de técnicas utilizadas por el director de un elemento del sistema para encauzar las actividades encomendadas al personal que dirige, de manera que puedan alcanzarse los objetivos establecidos en la forma más eficiente posible.

Control: conjunto de técnicas para comparar y evaluar las desviaciones probables entre los objetivos planeados y los resultados que se obtengan durante la operación del sistema.

Recientemente se han desarrollado las técnicas conocidas con los nombres CPM y PERT[3], que permiten realizar la planeación y el control con el grado de eficiencia y de detalle que se desee, y que son también de gran utilidad para diseñar la organización y las técnicas de motivación. Algunas de las técnicas descritas en el artículo 3 precedente, son también muy útiles para diseñar la organización del sistema o del elemento en cuestión.

6. ALGUNOS SISTEMAS DE OPERACION DECISIONAL EN INGENIERIA CIVIL

Los conceptos y técnicas descritas precedentemente son aplicables para el análisis, diseño y optimización de la operación de algunos sistemas de operación decisional de interés en Ingeniería Civil. Entre dichos sistemas pueden mencionarse:

a) Sistemas hidro-eléctricos [13, 14].
b) Sistemas de irrigación [13, 14].
c) Sistemas de transportes: carreteras, tránsito en ciudades, ferrocarriles, transportes marítimos y aéreos.
d) Sistemas de vivienda popular.
e) Sistemas de desarrollo urbano.
f) Empresas constructoras.
g) Empresas de estudios y proyectos.
h) Empresas productoras de materiales de construcción.

También son aplicables algunas de las técnicas descritas, para la dirección de la construcción de proyectos especiales o de producción masiva [15].

7 NECESIDAD DE UTILIZAR EN MEXICO LAS TECNICAS PRESENTADAS

El desarrollo económico de México en los últimos años ha traído consigo un aumento notable en el monto de las inversiones gubernamentales y privadas en sistemas de operación decisional de interés en Ingeniería Civil. Esto ha provocado la necesidad de analizar, diseñar, realizar y operar sistemas cada vez de mayor magnitud y complejidad en un tiempo reducido. Este hecho y la no utilización de técnicas como las descritas precedentemente ha sido la causa de numerosos fracasos presupuestarios, y del frecuente empleo ineficiente de los recursos disponibles.

En el futuro es probable que tengamos necesidad de realizar sistemas aún mayores que los realizados hasta ahora, y que tengamos también que aprovechar mejor los sistemas existentes. Las técnicas descritas nos permiten, en uno o en otro caso, lograr una mayor eficiencia en la utilización de nuestros recursos y consecuentemente, la posibilidad de lograr un desarrollo económico mayor y más acelerado.

La investigación, desarrollo y experimentación de las técnicas descritas ha requerido un gran esfuerzo económico e intelectual en otros países. Tenemos ya gente preparada en ellas y tenemos también los medios para aplicarlas, utilicémoslas en beneficio de México.

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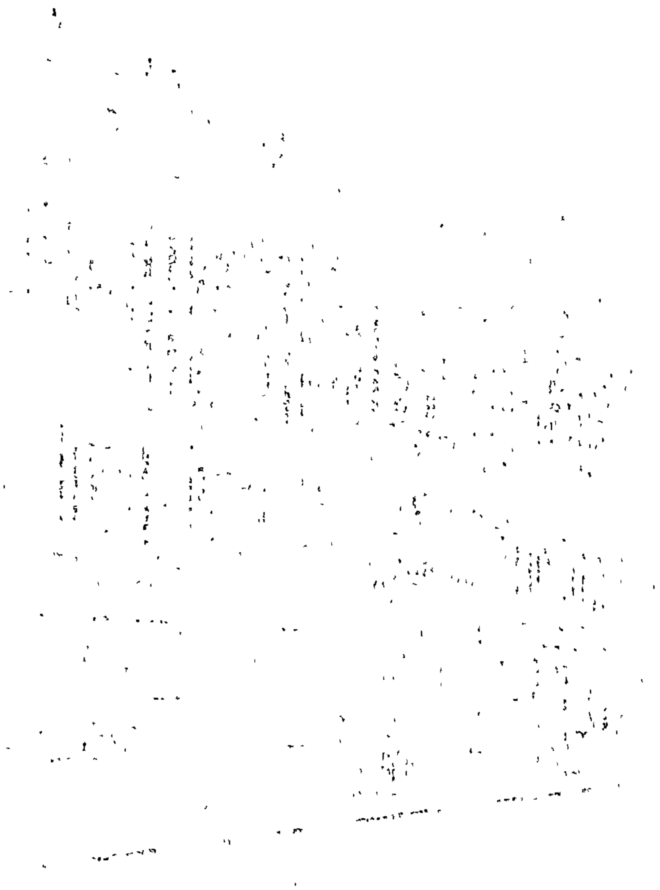

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3. URBAN SPACES AND STRUCTURES

Leslie Martin & Lionel March

Cambridge University Press, 1972.

2. Speculations†

LESLIE MARTIN, LIONEL MARCH & OTHERS

In the 1920s an important shift of architectural intention and process – a shift of social attitude – became clear. However complicated the historical situation may have been, three powerful lines of thought appeared. The first came from the passionately held belief that there had to be some complete and systematic re-examination of human needs and that, as a result of this, not only the form of buildings, but the total environment would be changed. The second line of thought, interlocking with this, was simply that change in the form of buildings, or environment, would only be achieved completely through the full use of modern technology. These two ideas produced a third, which was that each architectural problem should be constantly re-assessed and thought out afresh (Wurster 1965).

Now it is clear that no single one of these principles was ever completely demonstrated. They remained lines of action sometimes followed up separately, sometimes together. The rational examination of needs went some way, certainly, towards a fundamental change in the plan form of buildings. But of technical innovation, there was not a great deal. There was a lot of talk about the machine but its end products were not very evident in buildings. What the designers saw, often in a confused way, were the possibilities that arose from their beliefs and attitudes, and it is around these anticipations that they built up their formal systems. In this sense their buildings were symbols of what a new architecture might be. And for their day they had an immensely powerful meaning.

All this is something very different from an attempt to produce new forms as a primary objective: i.e. as a kind of rootless formalism. What seems to be important about it are the intentions that caused these forms. The difference between a chair produced by the arts and crafts movement and a chair designed by Rietveld is not just a difference of form. The form comes from a different emphasis on who makes it, on how it is made and how many people can have it. Now to stress this distinction is to make a declaration of attitude. The design of an object becomes a statement of conviction about what a society may need, the way it might consider its surroundings, the kind of products that it might have and how it might manufacture and use them. It is indeed an intellectual commitment; and this attitude of mind will apply equally to any aspect of design. The work resulting from the 1920s and 1930s is of interest and value today because of the ideas that it embodies (Wilson and Rowe 1965).

The change from art and craft intuition towards rational analysis, measurement, technical innovations and speculative thought about these things, is one manifestation of this. The change is there at an early date in the opposition to the intuitive craft approach, and in buildings that are 'built to a purpose' and thought out, rather than drawn. It is this matter-of-factness in which the act of design cannot be separated out as a form-making process that remains central. It is re-echoed in the various catch-phrases around which theory (and particularly German theory) was discussed.

But history is never clear cut. Against this attempt to reintroduce rationalism as a basis for architecture, there is, all along the line, the opposition of a powerful wing of 'individualist' creators. The situation is confused. Rational thought about needs and processes by one school was in some way considered by another to be dangerous and inhibiting. Practical reason and intuition were seen as opposites. And it is also true, as C. B. Wurster (1965) and J. M. Fitch (1965) have noted, that just as the products of practical reason were being demonstrated on an impressive scale in the housing projects of Holland and Germany, the developing theory became dogma. The principle that rational thought about use and construction must produce (as an integral part of this process) its own formal systems required a continuous reassessment of every aspect of a problem. Knowledge would be established by analysis, advanced by experiment and confirmed or corrected by test. A ruthless reassessment of each achievement was an essential part of this process. But, in that important and major housing achievement of the 1930s, the process stopped. The speculative thought that could have extended the range of built forms into totally new environments dried up. In Germany and elsewhere the set housing solution solidified into parallel rows of slab blocks.

The fact that this happened was of enormous consequence. The rational

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† This essay is a compilation from many sources. The introductory pages are from an article by Sir Leslie Martin entitled, 'Architect's Approach to Architecture', published in the *R.I.B.A. Journal*, May 1967. It introduces paraphrased excerpts from other papers and articles which are here presented as 'Speculations'. The word is fitting as the attempt was to raise questions which could only be answered by subsequent formulations.

approach was at once suspect. The end result of practical reason appeared to be sterility: and it was assumed that this could be countered only by intuitive processes – by feeling. Thus the old nineteenth-century oppositions were continued.

What was wrong with parallel slab layout was not the rational thought that it contained, but the failure to extend this by further speculative, formal invention. As A. N. Whitehead (1929) once pointed out, it is speculation that makes rational thought live: and it is rational thought that gives speculative invention its basis and its roots. To analyse, to measure and to rationalise the problem is an essential part of the process of scientific thought. And, in the scientific process, intuition (or what Alfred North Whitehead (1929) prefers to call conjecture or speculative reason) is itself entirely arbitrary unless it is guided by thought or system. Practical reason is the means by which methods are developed for dealing with different kinds of facts. Speculative reason is an extension of this into theoretical activity. Progress depends on a lively interest in speculative reason. Through the interaction of these two forms of thought, factual assessment can take its place within an overall scheme of things: speculative reason is 'robbed of its anarchic character without destroying its function of reaching out beyond set bounds' (Whitehead 1929, p. 66). Whitehead goes on to add that the massive advance of modern technology is due to the fact that these two forms of thought (rational and speculative) have again made contact. That, translated into architectural terms, is equivalent to saying that the rational understanding of a problem and the extension of this into speculative (intuitive) thought is one single process: that is, that thought and intuition are not opposed but complementary. We may recognise at once an older (pre-nineteenth century) concept of architecture in which the design process cannot be isolated from the thought processes by which the problem is analysed and solved.

The decisions that are taken about the planning of buildings, their form and the grouping in relation to the land available may be based on assumptions which appear to be eminently sensible and rational. However, rigorous reassessment – despite the initial form of refutation that it might assume – will always prove productive. The argument presented here is that things are not always what they seem to be. Refutation can begin as an intuition of imposture; but to prove that, speculation and rational formulations must be able to demonstrate first the fallacy and then alternative and more useful deployment. The fallacy may exist at any scale: of site resources assumed to be needed, of the relationship of rooms within the building to the corridor space connecting them, of grouped buildings to each other and to each other's uses, of buildings within the city and the streets by which they are connected.

It is particularly fortunate when out of speculation, research has its beginnings. The points here raised were formulated out of a series of separate studies as they arose from practical problems. Since they were not contained within a formulated body of theory they can best be described as speculations.

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Speculation 1 (Martin & March 1965)

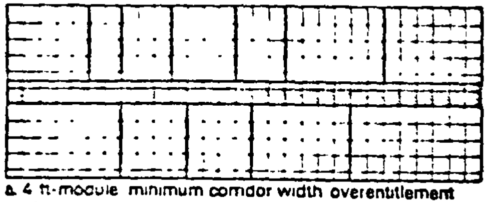
How can we study the efficiency of the planning of buildings? There is a common assumption that the most economic building is that in which the circulation space is reduced to a minimum when set against the total floor area: that is to say that maximum efficiency of planning is measured by the relationship of circulation to gross area. This measure is frequently used in assessing costs and awarding grants. At the same time other standards, possibly conflicting, may be introduced, for example room sizes based on increments, or constructional sizes resulting in modular dimensions. These are all interrelated factors and the interaction can be studied in a few simple diagrams.

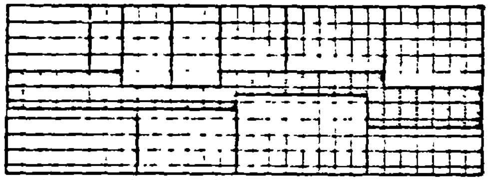
In the example selected, 12 rooms have to be accommodated. These vary in size and their areas are based on graded increments of 25–50 sq ft. The planning and structural module is based on a 4-ft grid. In the first layout (Fig. 2.1a), the rooms are arranged along each side of a minimum 6-ft corridor, in what may be considered to be an efficient plan. The rooms are made 18 ft deep and arranged in length to form the most convenient fit between the incremental sizes and the planning unit. There is a clear over-allocation of floor space per room: the area increment being 72 sq ft instead of the required increment of 25–50 ft.

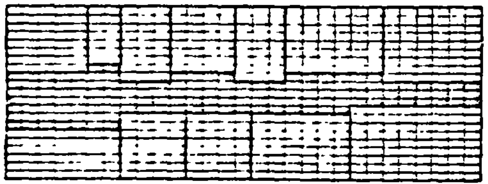
In the second diagram (Fig. 2.1b), the variation in room size has a two-way freedom, the depth of the room being controlled by the 4-ft module. The room over-allocation is reduced. The corridor is increased in space in what might appear to be a wasteful manner, but the total floor area remains the same as in the first example.

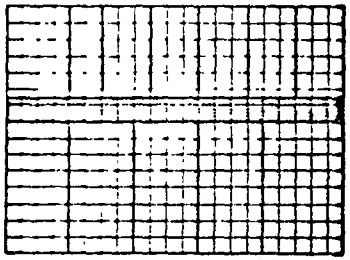
If the module for room depth is now reduced to 2 ft (Fig. 2.1c) then room allocation has a tighter fit. The corridor width is 8 ft over 80% of its length and may be more pleasant and at the same time more useful by accommodating waiting areas or filing space.

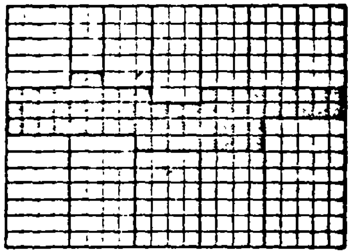
In the previous examples the building block is 29 units in length and 10½ in width. The effect of an increase in the width of the block can now be considered. In the next diagram (Fig. 2.1d), with the block now only 21 modules long and 14½ modules deep, a 6-ft corridor is again introduced. The over-allocation is now the highest in the series. The circulation area is the least and the external face is 16 modules less than in the previous examples.

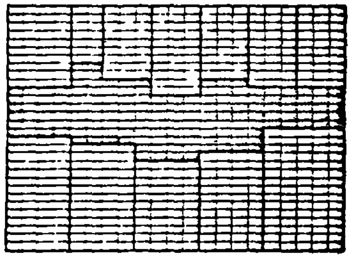

a 4 ft-module minimum corridor width overentitlement of room area


b. 4 ft-module, freedom of corridor width: reduction of overentitlement


c 2 ft-module increased circulation area: better entitlement fit


d block proportions changed, minimum corridor width reduced perimeter, highest overentitlement


e wider block on 4 ft-module, freedom of corridor width: closer entitlement fit


f wider block on 2 ft-module, increased circulation area. exact entitlement fit


g block width increased again, length decreased exact entitlement maintained, area utilisation increased, perimeter decreased, worst ratio of circulation area to gross area

Fig. 2.1. A comparative study of office layout with varying planning modules, room depths, and perimeter lengths.

If the rooms are now given freedom in depth and the depth is controlled by the 4-ft module (Fig. 2.1e), the room entitlement has a closer fit and the corridor is nowhere less than 8 ft wide. With a further reduction of module depth to 2 ft (Fig. 2.1f), there is no over entitlement and nowhere is the corridor less than 10 ft. When the block is widened again to 16 modules (Fig. 2.1g) the increased depth allows a conference room to be inserted in the central area. The external perimeter face is reduced from 42 modules to 38. By some criteria this layout is the best, though it has the least favourable circulation to gross area ratio (26.6%) in the series. It gives a perfect fit of entitlement to allocated space, has the least external wall surface (perimeter length) and the least gross area. The ratio of circulation to gross area as a measure of efficiency can certainly be questioned.

Speculation 2 (Martin & March 1965)

Many measures of the 'efficiency' of buildings may be developed but these can only be of use when they can be seen in relationship and when values can be defined in measurable terms. It may be asked, for example, what building forms make the best use of land? The question necessarily involves a value judgement of what is meant by 'best use' and this can only be answered objectively insofar as the values can be defined in measurable terms. It might be assumed that current planning controls, where they use measures, will supply an answer and that the question is asked wherever a development is proposed for a given site.

Current planning techniques, in fact, offer two measures which have dominated planning and architectural action for many years. The first is a measure of floor space index (or its alternative plot ratio) and the second is concerned with daylight considerations.† These two measures are assumed to provide a rational relationship of floor space to site and an assurance that buildings will be adequately lit. The use of the first measure has sometimes been extended to give an indication of the population accommodated in the buildings.

Martin, March and Taylor (1965) examined this last point by producing a set of graphs to show the relationship of three of the factors which may be considered in determining the population capacity of a given site. (These graphs are illustrated in Fig. 2.2.) In relation to a typical site area of 100,000 sq ft the plot ratio may be 2:1, 3:1 or 4:1. This generates floor areas of 200,000, 300,000 and 400,000 sq ft (Fig. 2.2a). The gross

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† Floor space index is the gross floor area measurement of the building including the thickness of the external walls; this total is divided by the site area including half the width of the surrounding roads. Plot ratio is the same gross measurement of floor area divided by the net site area. These measures are expressed as 2:1, 5:1 etc. Daylight considerations are measured by special protractors and nomograms.

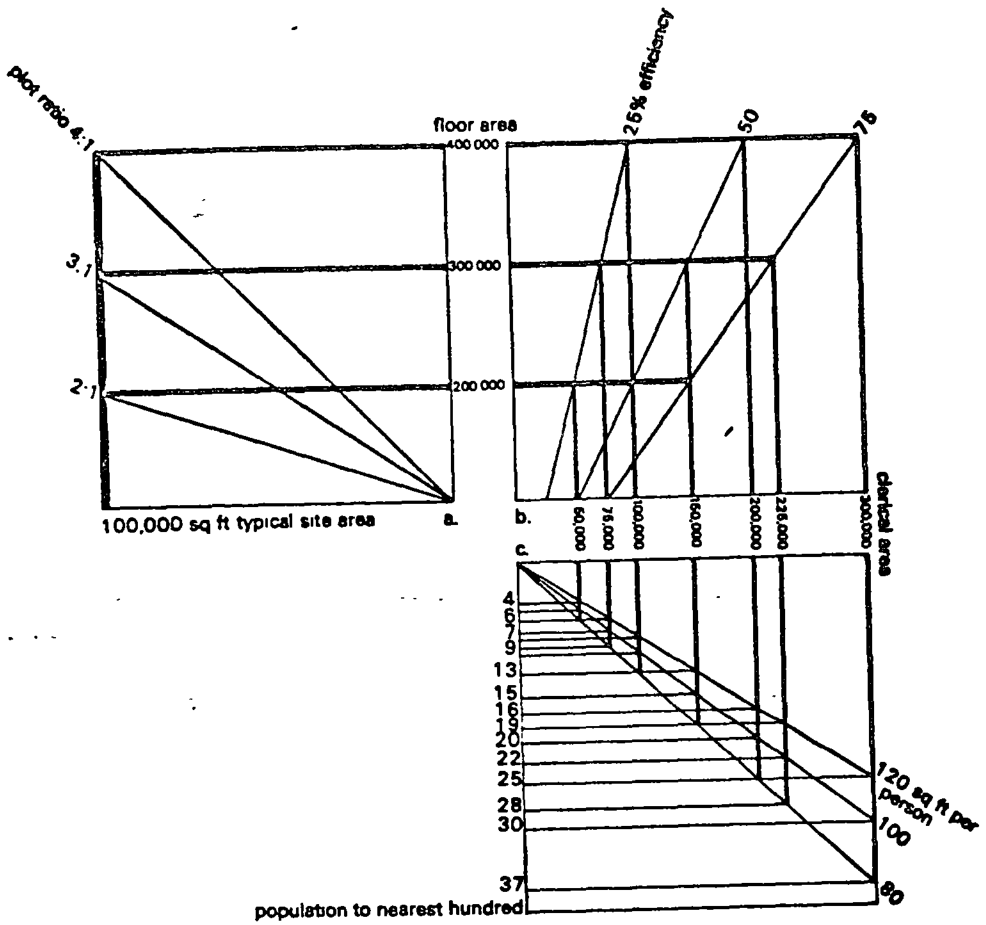

Fig. 2.2. Range of population density as function of plot ratio.

floor area may then be used with varying degrees of efficiency, for example 25%, 50% or 75%. The clerical areas generated from these (Fig. 2.2b) yield nine possible results ranging from 50–100,000 sq ft at 25%, 150–200,000 sq ft at 50% to 150–300,000 sq ft at 75%. If these possible clerical areas are now related to an allocation of square feet per person (Fig. 2.2c) this too may fall within allowances of 80, 100 or 120 sq ft per person. In this example seventeen different populations ranging from 400 to 3700 could arise from the same site area as a result of these relationships of plot ratio, general plan efficiency and floor space allocation per person.†

† Other factors will clearly limit this range, for instance, building codes. Similarly, land and development costs, particularly in central business districts, will tend to secure intensive use. But coordinated relationships between bulk and density and use and density are not usually even formulated.

It is clear that plot ratio in itself is no satisfactory measure of population, though it is useful as an assessment of the total floor space provided by buildings on any given site in any area of a town.

Speculation 3 (Martin & March 1966)

But continued scrutiny can go on to reveal whether this plot ratio measure will insure in any way that the site area will be effectively used. In order to demonstrate this we might place on any given site parallel rows of 4-storey buildings spaced apart by a conventional light angle of 45°: in this case the plot ratio will be 2:1. If however the building remains at 4 storeys but is arranged as a solid block lit by courts, in which the prescribed light angle is still used, the plot ratio will increase from 2:1 to 3:1, that is by a factor of 50%. Assuming for a moment that both forms of building lend themselves equally to internal planning, it becomes clear that the building form can have a pronounced effect on the total floor space possible on any given site. If urban land is to be developed economically and if reliable measures of this are necessary, it is desirable to know which forms of building appear to make the most effective use of ground area.

In approaching this question we are at once confronted with some deeply embedded ideas. One of these, for example, is the prevalent notion that high tower buildings are necessary in order to use land efficiently. Tower buildings have been used indiscriminately in London on sites which differ considerably in both size and surroundings. Any form of building is permissible within the measure of floor space index. If certain limits are set, such as size of site, the amount of floor space required, the acceptable depth of building, the amount of floor space with outlook, the amount without and so on, it is possible to demonstrate that a development might assume many building forms including tall towers and that a very considerable number of variables exist and a wide range of choice requires examination. In one case studied with six co-ordinates, this reached a total of 60,000 possible solutions.

Speculation 4 (Martin & March 1966)

How can such a problem be studied in a systematic manner? The site utilisation of various layouts can be studied by classifying the built forms under three headings: the pavilion or tower, the street and the court. These can be considered within a rectilinear universe. The pavilion is finite in its plan form. The street extends, potentially, infinitely along one axis. The court extends infinitely along two. From these built forms rectangular lattices can be derived. In fact the pavilion, the street and the court consti-

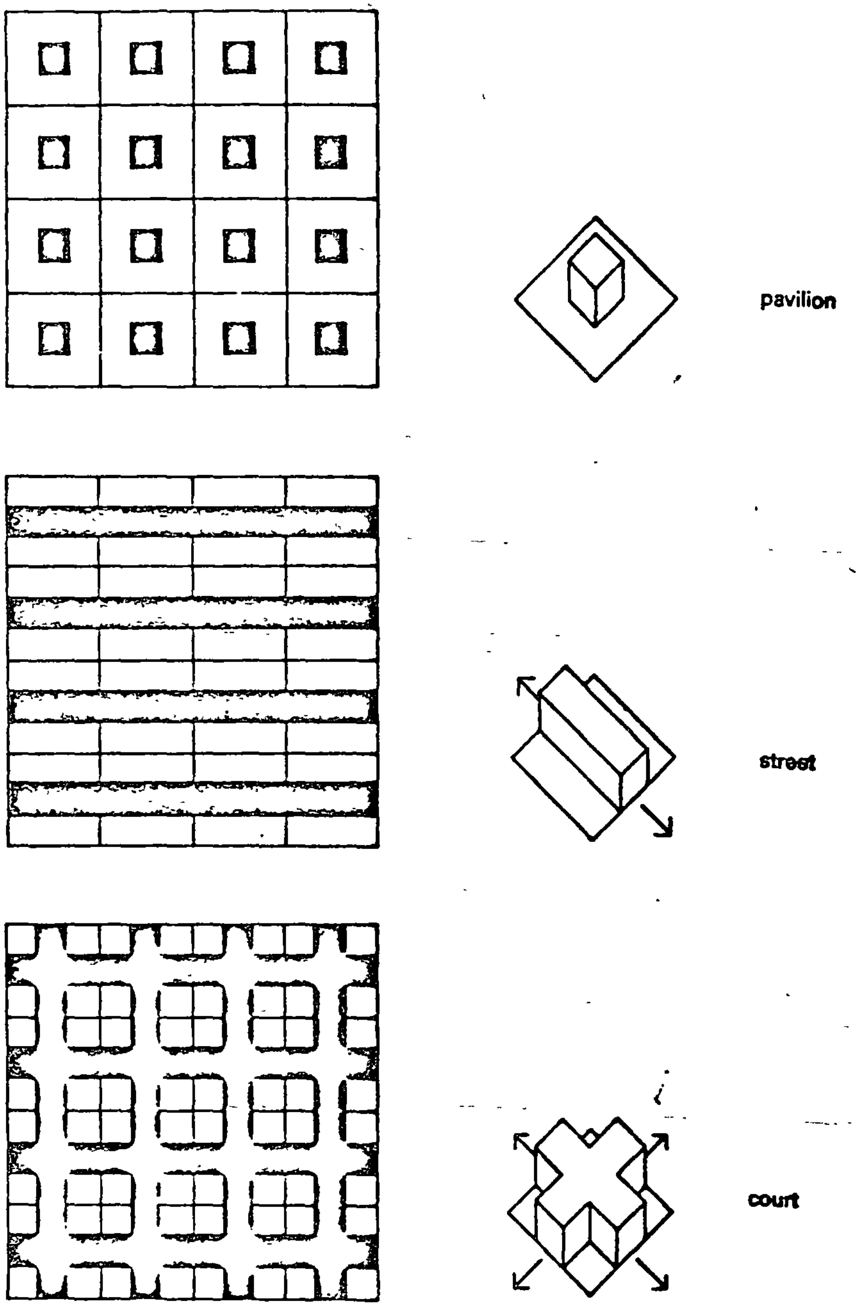

Fig 2.3. Schematic diagram to show three different dispositions of built forms: **pavilion** or tower, street or slab, and the generating cruciform in a continuous pattern of **courts.**

tute points of recognition in what may more properly be seen as a continuous transformation from one extreme to the other (Fig. 2.3); from an array of isolated blocks elongated into continuous parallel rows, and these joined in the perpendicular direction to form a net of courts.

This can now be examined. The co-ordinates used must be constant for each case: the same site area, the same block depth, the same width of interspace, the same floor height, etc. Two factors reveal certain aspects of the problem: one is the site utilisation factor, that is the ratio of the site covered to the area not covered. The other is the built potential, that is the ratio of the floor area of the built form to the site area.

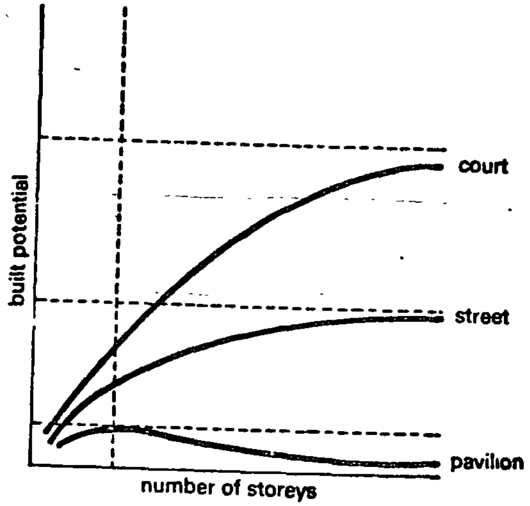

Fig. 2.4. Built potential in relation to number of storeys.

When the built potential is plotted against the number of storeys for each one of the three built forms described, assuming all other factors are constant, then it is seen that after a certain height the tower form ceases to use land with increasing efficiency and lower towers more closely packed together, but with no change in the angle between contiguous towers, will give the same degree of built potential. (Fig. 2.4) This could be one reason that the 'City of Towers', free-standing towers in a park-like setting, has never been built. It is inherently inefficient in terms of land use. In comparison to the pavilion or tower form at its maximum, the built potential of the street form has twice its value, and the built potential of the court form is no less than three times as great.

The form of a typical high density development, a low podium surmounted by a tower, corresponds closely to the building envelope obtained by using daylight protractors. Day lighting controls have determined to a large extent the massing of building seen in the central city of today (Watts, 1963). The type of study described can be developed by considering pyramidal forms which approximate more closely to the actual building form (Fig. 2.5). This generalised pavilion form may again be compared with its antiform, the court. When this is done, the court form is seen to place the same amount of floor space on the same site area with the same condition of building depth and in approximately one-third the height required by the pavilion form.

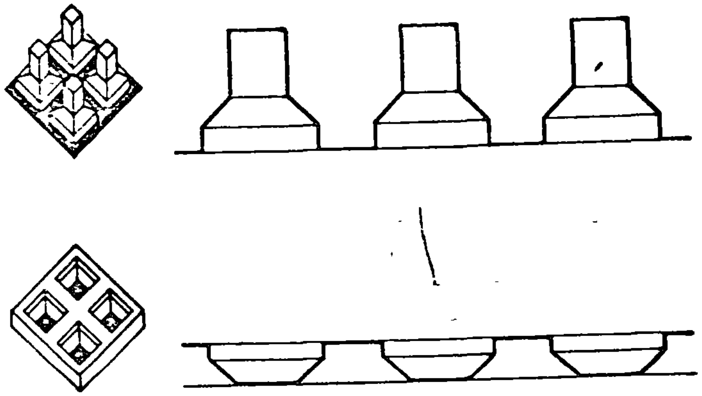

Fig. 2.5. Generalised pavilion form and its antiform; modified antiform of the generalised pavilion form at the same scale and containing the same amount of built volume on the same site; the heights are approximately in the ratio of 3:1.

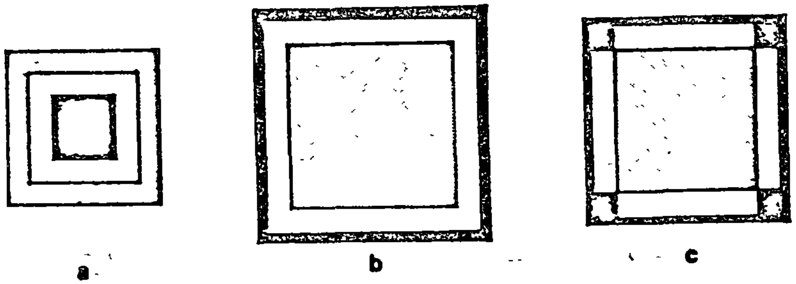

Fig. 2.6. The illustration shows (a) a pavilion development and (b) and (c) court developments, in which several proportions of site utilisation: coverage, built potential (bulk) and percentage of floor area without outlook, are the same. For the same number of storeys, the built potential will be the same for all three buildings. The different size site area needed to equalise these proportions suggests that each form has an optimum site size (Fig. 2.6c takes into account the internal angle condition required to maintain the proportion of floor space with outlook, while building the court form on a smaller site.) Black areas represent floorspace without outlook; white areas represent floorspace with outlook, tinted area represents that part of site uncovered by development.

Speculation 5 (Martin & March 1966)

What is to be observed, however, is that if the built potential is held constant for the pavilion and the court, and if the proportion of the built form having outlook and that with no outlook is again constant, then the size of the site for these two developments will differ (Fig. 2.6). This seems to suggest that each form of development probably has its own optimum size. If the highest densities were to be allowed only on the larger sites, then it appears to be the case that high and deep buildings would be unnecessary in terms of land use, though they may be required on other functional grounds. This kind of consideration could lead to the general loosening up of the texture of building on ground space. In that case a new relationship of building to road must be sought. The development of larger areas of land and the possibility of buildings occupying less ground space offers the possibility of a new scale of road network in which the interrelationship of land, building content and the traffic which it generates is made more balanced.

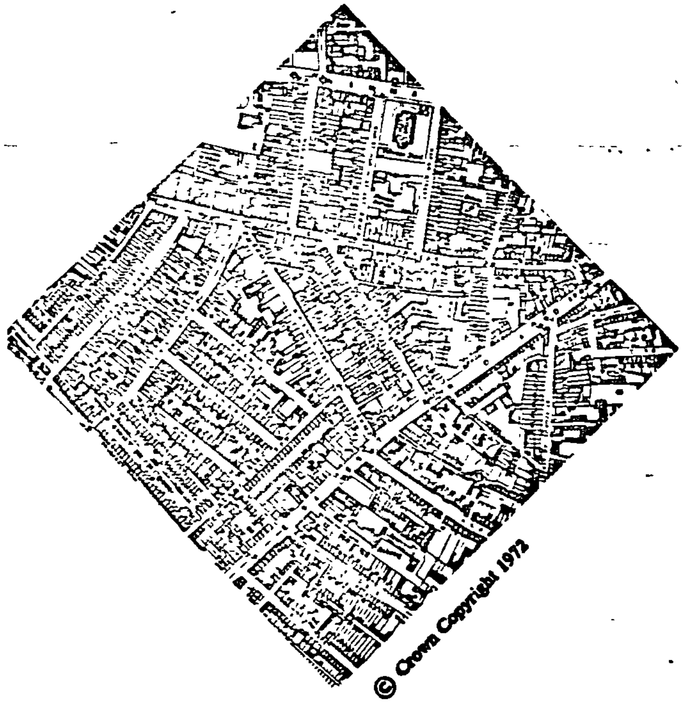

Fig. 2.7a. A 50-acre site developed with typical bye-law streets at a density of 100 persons per acre.

Speculation 6 (Martin & March 1968)

This question of the relatedness of things is central to the consideration of any single issue like the provision of housing, schools, open space or the roads by which they are served. All these things are aspects of the main problem of relationships: and by looking at a question in this way the old barriers created by zoning are immediately removed.

Professor Vaizey (1968) once stated that the older areas of towns may continue to have the oldest schools. The problem, he said, was that even if the housing priorities did not eliminate them, the larger sites which they tend to demand displaces the stock of housing.

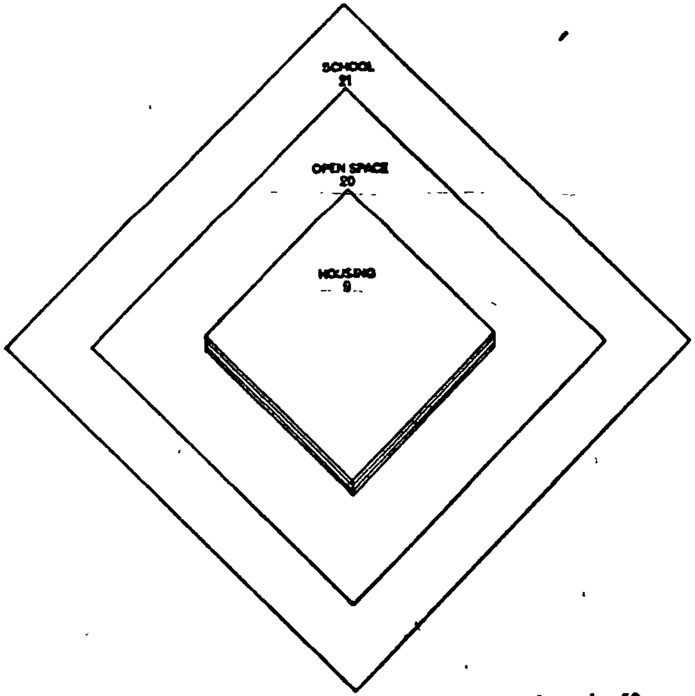

Fig. 2.7b. The land-use requirement of the 5000 people housed on the 50-acre site. The area allocated to schools includes 7 acres for buildings and 14 acres for playing fields. When an allowance is also made for open space, only 9 acres remain for housing. The housing floor area is 3 times that of the land available.

It could be argued that educational need and housing need cannot be separated: both are part of the larger theoretical problem of how we use land by buildings. When the issue is considered in this light the results are sometimes surprising. Consider an area of land in a nineteenth-century industrial city: suppose that there are 50 acres of by-law street housing inside a frame of busy commercial and shopping streets. (Fig. 2.7a). The residential density is 100 persons per acre. Assume that there is one obsolete primary school embedded in the housing: most of the children attend schools elsewhere. Now consider the rebuilding of this area. Can houses be provided for the present population at the same time that schools are made available for its children? There appear to be competing land uses, and in any rebuilding there may be the added requirement of public open space.

Let us look at this from the point of view of schools. Fifty acres generate 5000 people, and these in turn might demand an infants' school for some 300, a junior school for something over 400, and for the sake of argument we may assume also a secondary school of around 600. The school buildings alone would occupy 7 acres of land. Playing fields will require an extra 14 acres. Altogether 21 acres, or 42% of the land, would be required for educational purposes. If another 4 acres per thousand were to be claimed within the area for recreational needs, then 41 of the 50 acres or 82% of the land would have been pre-empted, and the housing would have to take place on the remaining 18%, on which again there would be some demand from access roads. In terms of sheer space the housing would occupy a solid block of building three storeys high (Fig. 2.7b).

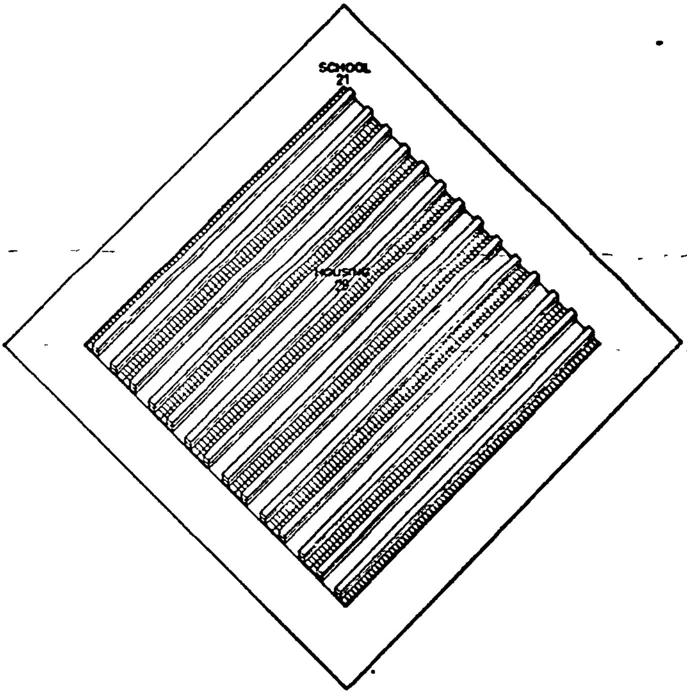

Fig. 2.7c. If the schools are accommodated, and this open space omitted, there remain 29 acres of land for housing. 3600 people could be accommodated in 2-storey housing arranged in the simplest possible way. 5000 people would require most of the site.

It certainly looks as though Professor Vaizey is right. It appears to be a matter of *either* housing *or* schools, but not both. But the quantification immediately draws attention to an important issue. Why is so much land needed? What is it that demands an area large enough to allow the simultaneous use by over 100 pupils playing five different soccer matches at the same time? What about overlapping uses of recreational land by a far wider range of activities – in farming terms, a double or triple cropping of the land? And if the school land were available to the locality or, as recommended by the U.S. Sub-Committee for Environmental Standards (American Public Health Association), if the schools used the recreational facilities provided for the neighbourhood, what saving of land would then be possible? It is clear that we have a choice: if we were to consider these relationships, Professor Vaizey's problem might still be soluble.

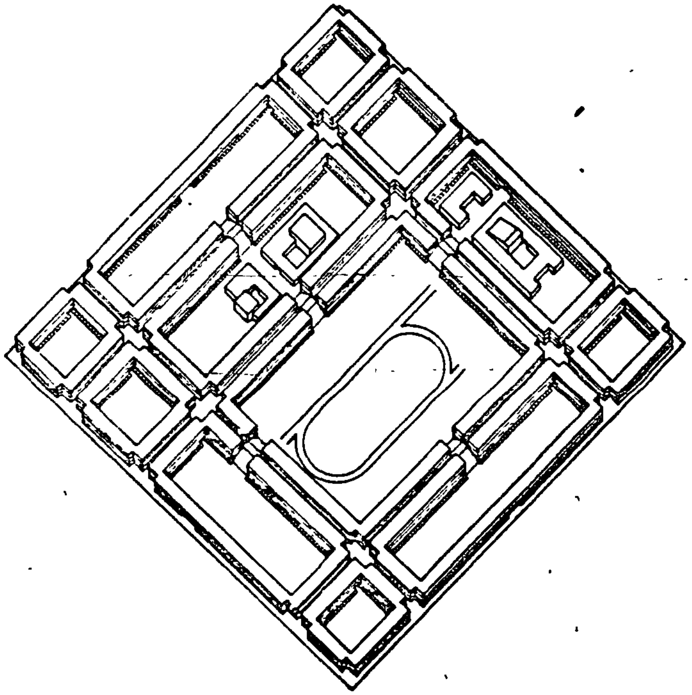

Fig. 2.7d. Three-storey housing would require 25 acres of land including roads and small 'outdoor' room space. This housing is only possible if the 21 acres of school land and the open space allocation are used to form 'urban rooms' of varying size.

But this can be looked at too from another angle, that of housing. A 50-acre site redeveloped at 100 persons per acre could be completely covered with houses and their attendant roads (Fig. 2.7c). In this case there would now be no sites for schools. But we now know that this type of layout is only one point of recognition in a spectrum of dispositions of built form on the land. This primitive layout shows housing for 3600 people in two-storey houses and 21 acres for school sites. But if some sharing of the school land and open space were acceptable, this combined-use land (Fig. 2.7d), could provide 'urban rooms' within the layout and the new distribution of built form could accommodate the total population of 5000 in three-storey houses. This corresponds approximately to the layout of some of the squares in Bloomsbury. (Fig. 2.7e).

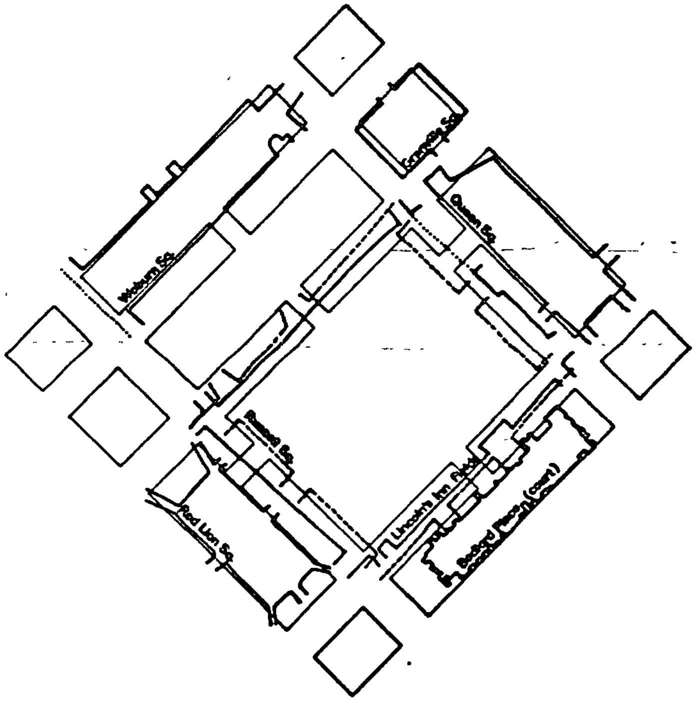

Fig. 2.7e. The 'urban rooms' compared with open spaces in the Bloomsbury area of London. Note that most of the buildings around the London squares exceed 3 storeys in height.

Accept another point in the spectrum and place the housing round the edge of the site (Fig. 2.7f and g): the total population of 5000 could be housed in narrow-fronted houses or flats, four or five storeys high around the perimeter of the site. They could all overlook and have available for use, a band of open space 180 ft wide and at the centre of this the 21 acres of land required by the schools. In this case both the housing and the schools could be provided.

Is it now preferable to accept a housing solution of this kind in order to find land for the schools? Is it really unacceptable to have a condition rather like that of overlooking Parker's Piece in Cambridge from some four or five-storey terraces around it?† (Fig. 2.7h.)

The proposition set by Professor Vaizey is clearly not insoluble. Both the housing and the schools can be sited, but not without adjustments within a total framework.

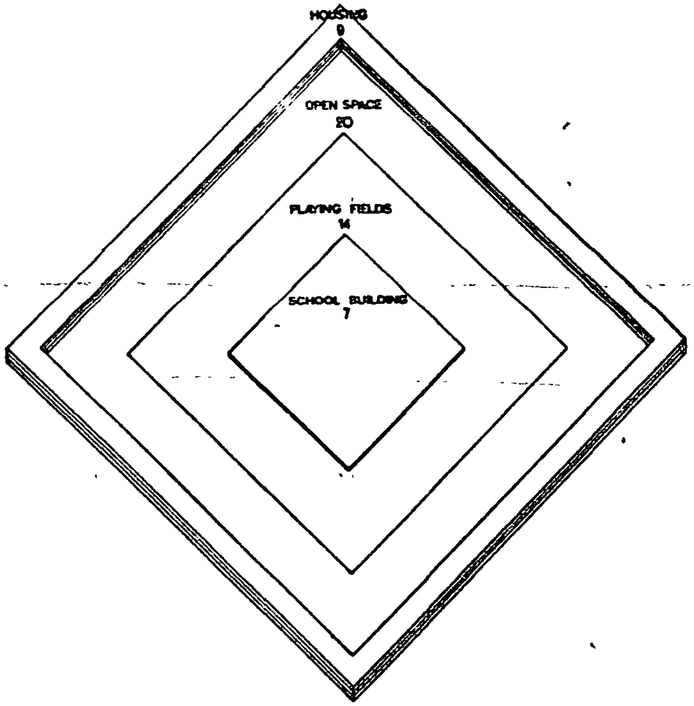

Fig. 2.7f. The housing area is now placed around the perimeter. If all other land uses are satisfied there remain just 9 acres of housing land.

Speculation 7 (Bullock, Dickens & Steadman 1968)

The lattices that can be built up around the 'pavilion', the 'street' and the 'court' forms (Bullock, Dickens and Steadman 1968, p. 104) are not arbitrarily chosen, but within the context of rectangular geometry, and treating prismatic forms only, they constitute the entire range of possible

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† The results appear to be very simple But it is curious that the forms of the layout described do not seem to have been built: at least not recently. Architects tend to think of housing in terms of building types: point blocks, slabs, maisonettes rather than land use built form relationships which may generate new types.

regular space-filling arrays. Despite their abstract geometry they indicate universal characteristics of the ways in which buildings use land and the forms are ones to which many actual buildings in the real world approximate.

In the development of this work March and Trace (1968) have formulated a mathematical description of built forms making it possible to give a standard notation to the geometry and other significant factors of these rectangular prismatic forms. This work has also been extended by the differentiation between perimeter space, that is unobstructed space around the building's edge, and core space which has refined the basic study.

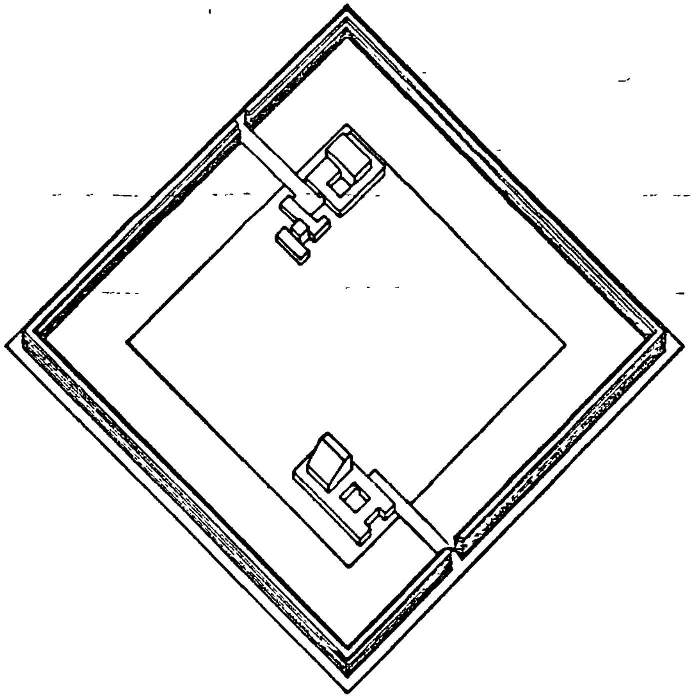

Fig. 2.7g. A 4½-storey narrow-fronted housing band could accommodate 5000 people at a density of 500 persons per acre. But they would all look out onto a vast open space: the perimeter open space is 180 ft wide and at the centre is the 21 acres of school land.

Nevertheless, evaluation of these basic forms is possible only in the simplest terms. The performance of forms may be compared, for example, in terms of the amount of land that they require to provide the same floor area: or the ratio of perimeter space to core space may be measured for different forms. Very general cost comparisons can be made by treating the cost of each building as a simple factor of the total floor area or by attempting to weight the costs to take account of the ratio of floor area to roof area, and of floor area to perimeter walling in order to give a limited understanding of the changes in cost with the change in form.

Such measures of performance are crude, however, and may provide the designer with information too coarse to use in modifying his preliminary hypothesis or even to allow him to detect the effect of many decisions. What is needed is a library of factors considered in such a relationship that a change in any one of the parts is immediately seen in its effect on all the others. This is something that the designer is usually unable to do and adjustments to design are made on the assumption that the change is largely independent of all but the most obviously related factors. The interdependence of the parts of the design problem and the validity of breaking the problem down into manageable but relatively independent parts has been studied by Christopher Alexander (1964). His work on the 'pattern of the content' seems essential as a first step to a consideration of the pattern of the form which is the problem that we are dealing with here. The total work of architecture is essentially concerned with the 'fit' between these two considerations in themselves and the technical methods through which their requirements are met.

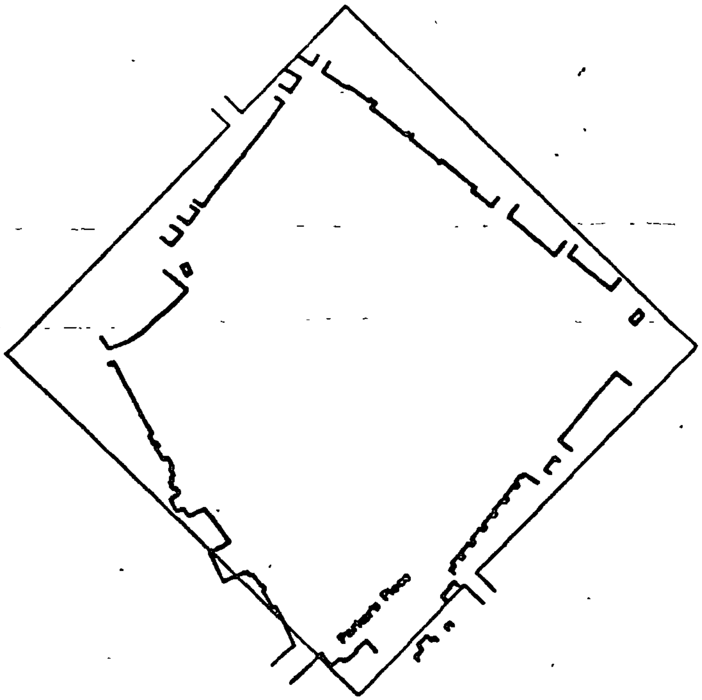

Fig. 2.7h. The central open space in Fig. 2.7g compared with Parker's Piece in Cambridge.

In order to monitor back to the designer information of sufficiently 'fine grain' to illustrate the real effect of the design decisions on the building, or to compare the 'fit' between activities and alternative building solutions, it must be possible to make a systematic transformation, not only of the overall form of the building, but also of the different elements of the building. It must be possible to compare not only different building forms but alternative room layouts, alternative structural and servicing systems and alternative circulation systems in sufficient detail to trace the consequences of these choices on the performance of the building in relation to the activities which it serves. That is the problem that needs systematic formulation if we are to increase our understanding.

Speculation 8 (March 1967)

The systematic study of the pattern of the form is relevant to the building, to the group of buildings and to the city or the urban region. And it is equally revealing in each case.

Figure 2.8 is a version of Howard's cluster of towns forming a city federation of 250,000 persons. By the year 2000 we would need 250 of these clusters to accommodate the whole expected population of England and Wales. Suppose for a moment we built these clusters and demolished everything else. 250,000 people would live in easy reach of one another and all social facilities. Schools would be within walking distance of all homes. Shopping would take place indoors. Everyone who wanted to would have a house and garden. The minimum plot size is 20 ft by 100 ft. The roads would easily accommodate the motor car. The towns have hollow centres and the road system is more like a simple grid wrapped round upon itself than a radial and circumferential system. The minimum road width is 60 ft whilst the six principal boulevards are 120 ft as are the two principal avenues. The nation would then be living in towns, which could accommodate the motor car yet be small enough to permit easy pedestrian access to many different functions. Everyone would be able to own a house and garden. Yet the really remarkable thing about the proposition is this: 4,000,000 acres of land that is expected to be built on by the year 2000 would not be required. In fact, although the population would be twice the size of that of Howard's day it would have been accommodated on the same land as was urbanised in 1898. Since then the urban land stock has doubled, and it is expected to have trebled by the year 2000. Howard cannot be charged with any waste of land.

A simple question that can be asked is this: if every household in the

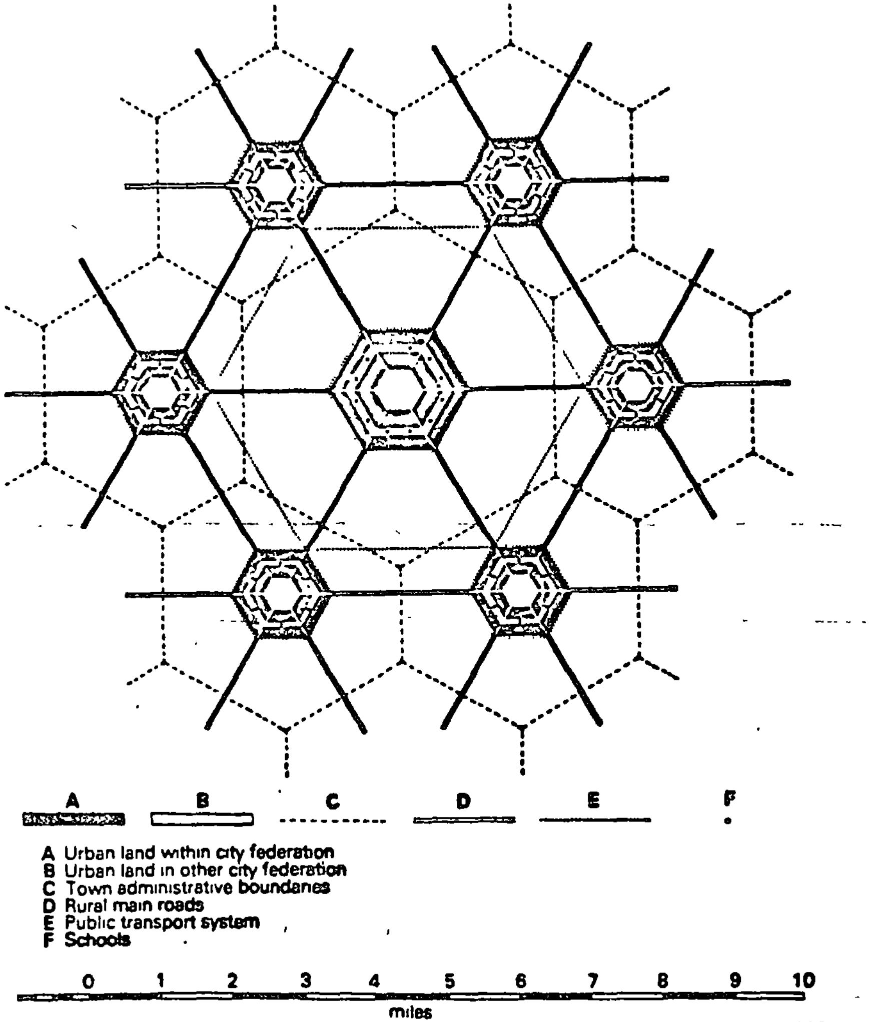

Fig. 2.8. Ebenezer Howard's cluster of garden cities forming a city federation of 250,000 persons.

year 2000 could have a house, a garden and a car on 2,000,000 acres of urban land, why will they not have a house, a garden and a car on three times as much? A more equitable distribution of land would ensure a house and a garden for all who want one. Yet, even if land were not distributed evenly, this simple desire could be answered to some extent by more rational land use planning in relation to the built forms required for the house and garden.

First let us look at how 10% of a land area might be covered by urban

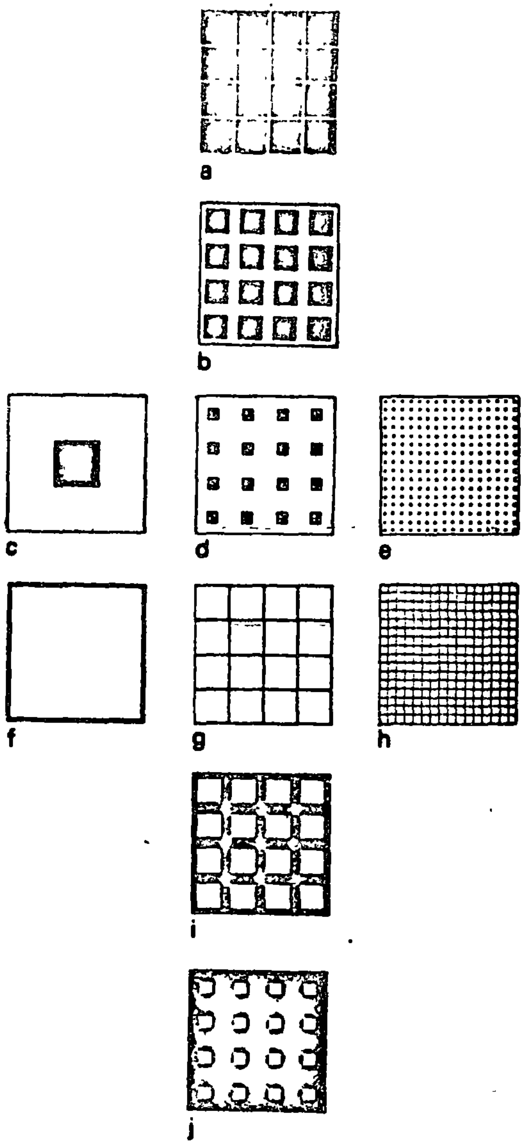

Fig. 2.9. Range of nucleated and linear distributions from 10% to 9% coverage.

uses. This 10% is the present proportion of urban land to all land in England and Wales and it includes urban open spaces like parks, but not agricultural land within urban administrative boundaries. Fig. 2.9c shows the 10% coverage distributed in a concentrated nuclear form (one single blob) and Fig. 2.9e in a dispersed nuclear pattern (in this case 256 blobs).

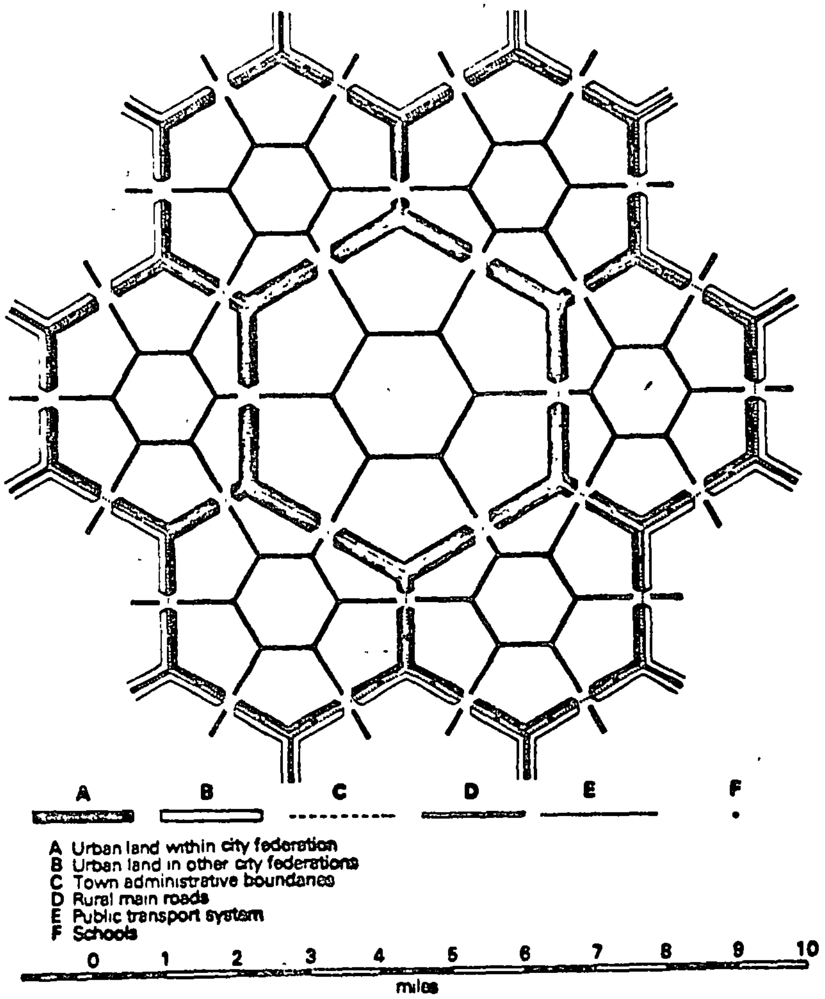

Fig. 2.10. Linear antiform of Howard's city federation.

Figs. 2.9f–h, however, show the same amount of urban land distributed in a linear manner: The pattern illustrated in Fig. 2.9f may be described as concentrated linear (a coarse mesh) and Fig. 2.9h as dispersed linear (a fine mesh). Fig. 2.9a shows 90% coverage, while Figs. 2.9i and 2.9j show the inverted scheme of linear coverage.

There are three properties of the distribution. The topological property of being nuclear or linear corresponds to thinking blobs, *or* thinking of the spaces between. The second property is concerned with scale. The property of being concentrated or dispersed is dependent on the scale chosen to observe the pattern. If, for instance, 1/256 of the dispersed blob pattern (9e) were to be seen at close range, it would look exactly like the concentrated blob pattern (9c). The only difference is one of scale. The third property is the amount of coverage. This can be high (90%) or low (10%). So far no set population has been given. Assume that it is fixed and is independent of land coverage. It will be clear, with a fixed population, that if the land coverage is high (90%) the gross residential density will be relatively low and proportional to 100/90 = 1.1. If, on the other hand, the land coverage is low (10%) the gross residential density will be high and proportional to 100/10 = 10. This low coverage is associated with high density. But the important point is that the notions of concentrated or dispersed developments have no relationship to population density. It is as possible to have a high-density dispersed pattern as a low-density concentrated pattern.

Next, if the pattern is assumed to be continuous and isotropic there are just three geometric arrangements – triangular, rectangular or rhombic, and hexagonal. For the sake of simplicity the rectangular pattern is used here with the sole exception of the next example. This shows (Fig. 2.10) the think-line version of Howard's city federation. Exactly the same proportion of land is urban here as in the think-blob arrangement, and approximately one-quarter of this urban land is open space. It is not solidly built-up.

It can be shown mathematically that the schools are likely to be more accessible in the linear form. The same is true of any other social function that is distributed evenly with the population. But perhaps the most significant difference between the two arrangements is that in the nuclear pattern driving across country requires movement across the town (or alternatively the construction of a special ring road), whilst the linear pattern is interrupted only briefly by urban development and, if the urban parks are placed at these points, cross-country routes need not pass through built-up areas at all.

Speculation 9 (March 1968)

Next consider the correlation of residential building forms and density. The present housing yardstick, for example, implicitly assumes that as densities increase houses decrease in favour of flats, and low buildings give way to high. This is only true because of the professional separation of land use planning from its architectural implications. With favourable land use planning, semi-detached houses can be built at 200 persons to the acre. Three-storey terraces under more normal circumstances can be built up to 265 persons per acre. These are facts. Thus, instead of permitting the highest densities in the countryside where they can make the greatest sense, we insist on putting the highest density towards the centres of our cities.

This tendency may be represented by considering a city marked out from its centre in equal width bands (Fig. 2.11a). Each of these bands accommodates an equal amount of built space. Close to the centre, the built space will have to be achieved in the sky whilst on the perimeter this same quantity of space will be found on the ground. In conventional terms, if the plot ratio is 4:1 in the centre it will be, at the 9th and outermost ring, only 0.055:1, or if a building on the outskirts is one storey high, at the centre 72 storeys will be required. Abandoning the density cone concept, the whole built form could be disposed at an average plot ratio of 0.11:1 (Fig. 2.11b), or just twice that of the 9th ring. This plot ratio of 0.11:1 is only marginally higher than the mean of the four outermost rings, but a great deal lower than the mean of the five inner rings. Fig. 2.11c shows the same built space distributed in a linear form. Closeness and accessibility of similar functions are likely to be improved in a linear route development and since skyscrapers do not use central land very efficiently, the only sense that high buildings make in nucleated centres is in terms of real estate speculation. In terms of accommodating built space on urban land they are extravagant and irrational gestures. To return to housing densities, there is not much point in thinking of densities as great as 200 persons per acre (when the mean density is likely to be not more than 25 persons per acre in the year 2000), if it were not that by taking extreme situations it is often possible to see principles more clearly.

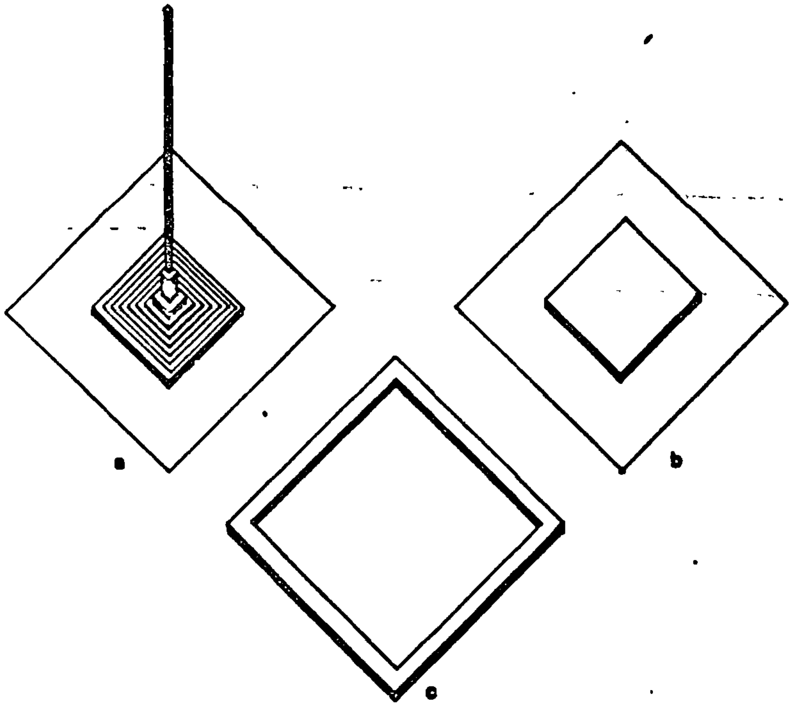

Fig. 2.11. Housing density in relation to its distribution.

Speculation 10 (March 1967)

In the study of Hook New Town, 16 acres of open space (including recreational areas) were allowed for every 1000 persons. At this rate 1280 persons would require about 20 acres, or a space 900 ft square (Fig. 2.12a). These persons could be housed in a ribbon of 3-storey housing with a small garden at 200 persons to the acre around their own public open space. The spatial effect would be like Parker's Piece in Cambridge. The access road would be like any simple terrace development. When one considers just how complex housing at this kind of density has become, it is timely to ask whether more might be achieved by a return to relaxed simplicity. A further modification is shown in Fig. 2.12b where all the houses might have a view of the countryside.

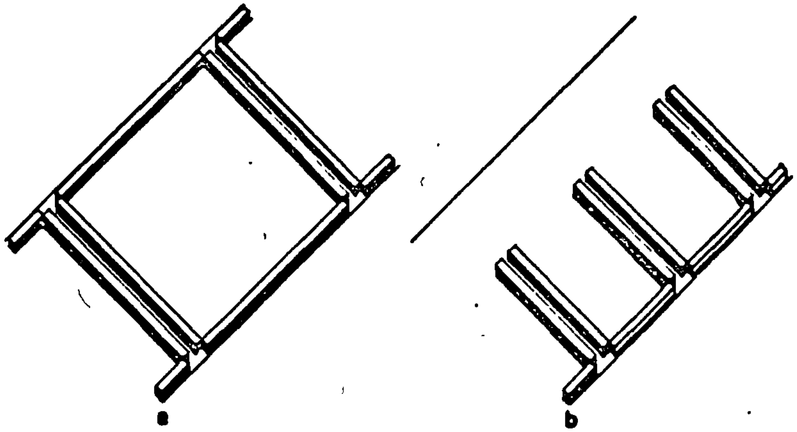

Fig. 2.12. Simple high density housing forms.

In all this the rural districts have a tremendous part to play. Already they are developing more rapidly than the urban areas, excepting the new towns. It is there that the new city is emerging. What pattern will it take? There are many excellent geometrical reasons, especially of a probabilistic nature, to suppose that a free, loose development along a network of routes has advantages of capacity, accessibility, density and use distribution not possible in nuclear development and that, with a positive policy towards open spaces, it is likely to prove the most reasonable form for the emergent city.

But planners will never know until the capacity has been developed to understand and measure the forces that are at work and to compare alternatives.

Speculation **11** (Martin 1968)

In order to find the full implications in the measurement and invention of built forms it will be necessary to use the techniques that have been developed in other disciplines and which are capable of describing highly complicated situations with greater certainty and clarity. Beyond this it is necessary for such techniques to demonstrate the relationships between different factors and the way that they affect each other. And finally it is necessary to be able to assess more accurately the effect of change. By means of such techniques it becomes possible to represent aspects of the world around us in highly complex models within which the relationships of all the measurable elements can be seen.

Econometrics, the 'mathematical movement' in economics, is only one of a number of developments in many spheres of thought in which an effort is being made to find a structuring theory of organization around which growth and change can develop, and to make this precise by mathematical expression. It has happened within the last half century and mainly since the war. The change has been profound. The description of this change by Stone (1966) with its emerging possibility of integration between studies which are now specialised and separate, has its parallel in urban geography (Robson 1969) and its various extensions.

The use of a mathematical formulation in the attempt to describe the ordering structure that lies behind a building or a city can be seen as another aspect of that texture of relationships through which we try to understand the complexity of an urban area. In developing such a study, the specialised division between architecture and planning has no particular significance and the developing language would take a form which others, notably the geographers and economists, are already using.

3. *Elementary models of built forms*

LIONEL MARCH

Much of our knowledge in architectural design is vaguely and qualitatively stated. Statements prevail such as 'high tower blocks make good use of land', or 'cube-like buildings are cheaper to build and run'. Design lore abounds in rules of this kind. Their authority rests more on intuitive conviction than on theoretical demonstration. Yet, as Edward Kasner and James Newman emphasise throughout their classic *Mathematics and the Imagination*, 'our *intuitive* notions about space almost invariably lead us astray'.

One problem which graphically reveals this point is quoted by Kasner and Newman (1949):

> In a room 30 feet long, 12 feet wide, and 12 feet high, there is a spider in the centre of one of the smaller walls, 1 foot from the ceiling; and there is a fly in the middle of the opposite wall, 1 foot from the floor. The spider has designs on the fly. What is the shortest possible route along which the spider may crawl to reach his prey? If he crawls straight down the wall, then in a straight line along the floor, and then straight up the other wall, or follows a similar route along the ceiling, the distance is 42 feet. Surely it is impossible to imagine a shorter route! However, by cutting a sheet of paper, which when properly folded, will make a model of the room [see Fig. 3.1], and then by joining the points representing the spider and the fly by a straight line, a geodesic is obtained. The length of the geodesic is only 40 feet, in other words, 2 feet shorter than the 'obvious' route of following straight lines.
>
> There are several ways of cutting the sheet of paper, and accordingly, there are several possible routes, but that of 40 feet is the shortest; and remarkably enough, as may be seen from cut *d* [in Fig. 3.1], this route requires the spider to pass over five of the six sides of the room.

This illustration is an adaptation of one of Sam Lloyd's famous teasers. It is solved by firstly sifting out the elements and relationships essential to the problem (there is no need to be concerned, for example, that the spider is hungry, or that the thing on the far wall is a fly, or that the wall is in fact wall) and then by secondly setting up a model of the structural facts (in this case a material analogue model (see below Chapter 7), which, thirdly, is sufficiently representative yet manipulable to allow the problem to be simplified in order to proceed to a solution (our paper box may be easily thought of as a room, but unlike a real room it can be unfolded and spread out flat in such a way that the original three-dimensional problem is reduced to a somewhat trivial two-dimensional one).

Buildings are complex artifacts. Most are unique. Generalisations about buildings are not easy to make. It may help to look instead at *built forms* which are not buildings. Built forms are mathematical or quasi-mathematical models (Chapter 7) which are used to represent buildings to any required degree of complexity in theoretical studies. Built forms, then, are designed and defined specifically for each study. Usually a study starts with somewhat hazy notions. To proceed, it is necessary to make some assumptions both to simplify the problem and to make it amenable to mathematical treatment. Appropriate variables must be selected and relationships established between them. And after some fact or other has been demonstrated, it is necessary to reconsider the original assumptions with a view to developing the model further to give a truer picture.

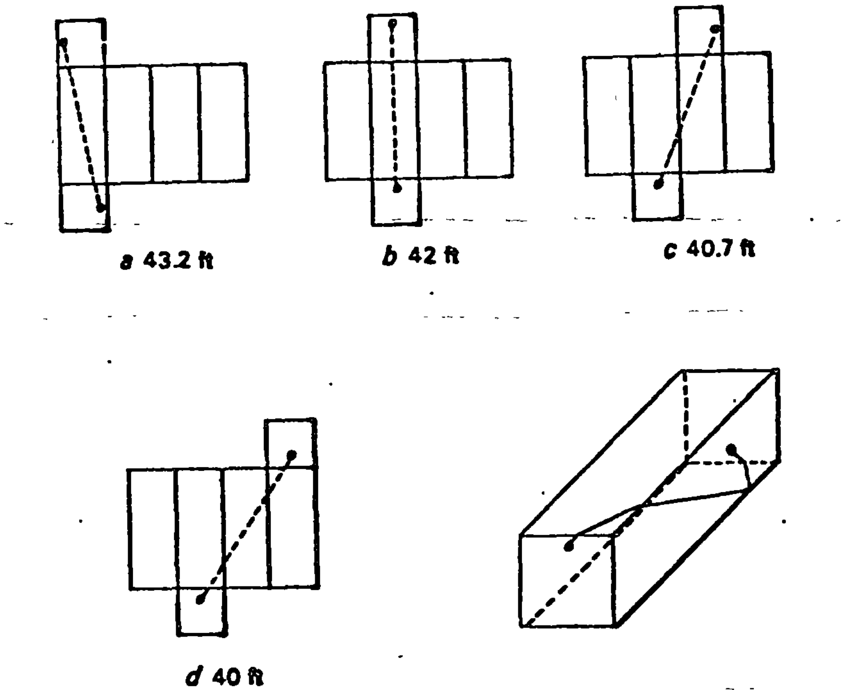
a 43.2 ft
b 42 ft
c 40.7 ft
d 40 ft

Fig. 3.1

Many problems in theoretical architectural studies will find suitable expression in terms of the 'new' mathematics. Some indications of the relevance of group theory, set theory, graph theory, of transformation geometries and so on are to be found in a recent book, *The Geometry of Environment* (March and Steadman 1971). Here, however, in this skirmish into mathematical modelling of the built form the mathematics are confined to more traditional methods. In this way it is hoped that older readers who have little background in the new mathematics will be able to follow the mathematical arguments and abstractions in the examples. Basically, the kind of advanced level mathematics covered in The School Mathematics Project: *Calculus and Elementary Functions* (Montgomery and Jones 1970) will be used.

In this latter book, the authors specify a general drill to be used when faced with a problem rather vaguely stated:

> (i) Make initial assumptions to simplify the problem, and make it mathematically manageable.
> (ii) Choose a dependent variable which will give an answer to the problem. (Often this is clearly implied in the problem itself.)
> (iii) Make a list of the variables on which it depends.
> (iv) Investigate the connections between these variables. (Often – almost always at this stage – we will find that having chosen one of them, we can express all others in terms of it. If this is not so, it may be because our original assumptions were not sweeping enough; or because we have failed to make use of some of the conditions of the problem. Such a condition might state, for instance, that the volume of a variable solid is constant. In this case, give a name to the constant, and express the condition as a mathematical formula.)
> (v) Choose an independent variable, express all other variables in terms of it, so that the original dependent variable (see (ii)) can be expressed as a function of it. (Make sure that the expression defining this function contains none but the independent variable and constants.)
> (vi) Note the domain of the function, from the conditions of the problem.
> (vii) Analyse the function, sketching its graph, and noting conclusions.
> (viii) Return to the original assumptions and see whether they can be improved to give a more realistic picture of the problem.
>
> All this may be described as giving a problem only vaguely stated a decent mathematical clothing. It has become common to describe it all – or the outcome of the initial stages – as a 'mathematical model'.

This procedure is best illustrated by a number of examples.

Example one

What shape should a building be to reduce heat losses?

Like many problems coming from outside into the mathematician's province, it is not all that obvious what is being asked for. As Montgomery and Jones (1970) point out, our immediate instinct will be to reply with a number of facile 'it depends-ons': 'It depends on the use of the building; on the method of construction used; on orientation or the local climatic conditions.' And there will always be someone who will insist that this is the wrong question to ask anyway: shouldn't we be finding out what kinds of buildings people think they feel comfortable in.

But these instincts should not immediately be succumbed to if the more modest goal of formulating a theory about a vaguely stated problem is adhered to – otherwise it becomes progressively necessary to take on the whole world without having achieved even one small but sure step forward in our understanding. The essential nature of the problem is clear enough and so is the context. It could be argued that since the sphere is a volume with a minimal surface area, spherical buildings would be a good idea, or if that is not practical why not a hemispherical building, or a cylindrical one? But most buildings, for many practical reasons, are rectangular in shape and therefore it can be assumed that the building chosen will be a simple rectangular block, that its volume will be constant (which is to say that if the floor to ceiling height is constant within the range of buildings considered, then all will have the same floor area), and that those proportions of length, width and height are being sought which minimise heat losses.

These assumptions define the nature of the problem. Buildings, however, even simple rectangular ones, have complicated fenestration patterns, upstands and tank houses on the roof, and all kinds of unique design features. Agreed it is these particular features that make each building interesting and which call our attention as we pass by in the street, but these curious irregularities must not confuse the search. For the purposes of this exercise a model is constructed of a building – a built form – which is a perfect rectangular parallelepiped each surface of which is considered to be made of a homogeneous material with a given thermal transmittance value. It is assumed for the time being that all other factors are negligible compared to the heat losses through these idealised surfaces. These initial assumptions at least have the merit that the mathematics they give rise to are manageable. Thus,

(i) The building is assumed to be a simple rectangular parallelepiped with homogeneous surfaces and constant volume.

(ii) The dependent variable chosen is some measure of heat loss which may be called q units.

(iii) Heat loss is dependent on the surface area and thermal transmittance of each face of the built form. The surface areas of the faces are dependent on the dimensions x, y, z of the block and the thermal transmittance of each face (which for the moment can be assumed to be equal) for the walls and roof, but zero (no heat loss) for the ground floor. Let the transmittance be U units (Fig. 3.2).

(iv) An equation connecting these variables can now be written:

$$q = \{2(x+y)z+xy\}U \tag{1}$$

since there are two faces of area xz, two of area yz, and just the roof area xy all with thermal conductance of U. Further, however, it is known that xyz, the volume of the built form, is constant. Let V be the volume, and then

$$V = xyz. \tag{2}$$

(v) In this example the choice cannot be limited to just *one* independent variable. There are two equations with three unknowns and no more can be done than to eliminate one of them. Let z be expressed in terms of x and y. Then

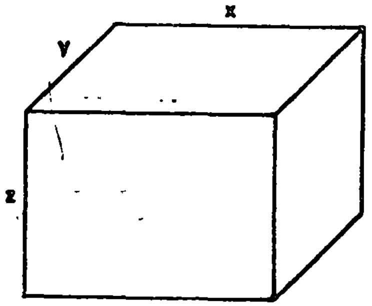

Fig. 3.2

$$q = \left\{2\left(\frac{1}{x}+\frac{1}{y}\right)V+xy\right\}U. \tag{3}$$

This is as much as can be done.

(vi) It is clear that x and y are positive quantities; but there are no other restrictions on their size. If x is very large, y will be correspondingly small for any given value of z and so on.

(vii) In the usual way, to find the minimum values of q the previous equation is differentiated in (v) with respect to both x and y, setting the results equal to zero. Thus,

$$\frac{\partial q}{\partial x} = \left(-\frac{2V}{x^2}+y\right)U = 0 \tag{4a}$$

$$\frac{\partial q}{\partial y} = \left(-\frac{2V}{y^2}+x\right)U = 0, \tag{4b}$$

whence $x = y$ at the stationary value. If the curve is plotted (Fig. 3.3)

$$q = \left(\frac{4V}{x} + x^2\right)U, \tag{5}$$

by substituting x for y in Equation 3 above, the stationary value is indeed a minimum value. And so a minimum has been obtained in which

$$x^3 = y^3 = 2V \tag{6}$$

as well as where the constraint $V = xyz$ holds. Hence, for minimum heat losses

$$x = y = 2z = (2V)^{1/3}. \tag{7}$$

From this it is seen that, to reduce heat losses, in a building whose exposed surfaces have equal thermal transmittance and whose floor conducts no heat, the best shape is square in plan ($x = y$) with a height just half ($z = x/2 = y/2$) the length of its sides: that is to say, a half-cube.

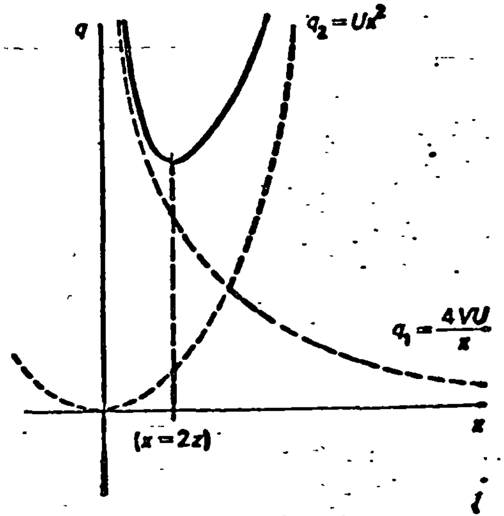

Fig. 3.3

(viii) Returning to our original assumptions. One assumption seems particularly arbitrary. It concerns the transmittance values. For one thing, ground floors do lose heat. For another, different walls will have different average transmittance values, not only because they may be constructed differently with varying proportions of fenestration, but also because of their exposure and orientation which gives rise to particular external surface transmittance values (Fairweather and Sliwa 1969). The roof, of course, can be expected to be different from the walls.

The model can be generalised and the notation can be modified for more concise expression. Call x, x_1, and y, x_2, and z, x_3. In this way a *typical* dimension may be referred to as x_i, where i may be either 1, or 2, or 3. Now let (i, j, k) be a permutation of (1, 2, 3), so that when specific mention of the jth and kth dimensions is made, it is clear that the ith is omitted: for example, 2 and 3, not 1; or 1 and 3, not 2. Let the transmittances of the two walls defined by the jth and kth dimensions be U_{i1} and U_{i2} respectively, and let U_i be the mean value of these two transmittance values so that

$$U_i = \tfrac{1}{2}(U_{i1} + U_{i2}). \tag{8}$$

The relationship expressed by Equation 1 above may now be generalised to read

$$\begin{aligned} q &= (U_{11} + U_{12})x_2x_3 + x_1(U_{21} + U_{22})x_3 + x_1x_2(U_{31} + U_{32}) \\ &= 2(U_1x_2x_3 + x_1U_2x_3 + x_1x_2U_3) \\ &= 2V\left(\frac{U_1}{x_1} + \frac{U_2}{x_2} + \frac{U_3}{x_3}\right), \quad \text{since } V = x_1x_2x_3. \end{aligned}$$

This may be written more compactly

$$q = 2V\Sigma_i \frac{U_i}{x_i}, \quad \text{for } i = 1,2,3. \tag{9}$$

The most obvious thing to notice about this equation is that, unlike its predecessor (Equation 1), it is symmetrical with respect to all the x_is (that is, x, y and z in the former notation).

For the mathematician this is always a satisfying state of affairs: a kind of democracy of variables. Previously (Equation 3) z was picked out as the variable to be expressed in terms of x and y, and this could be done again, but for the sake of symmetry use will be made instead of an elegant way of finding the minimum value of q first proposed by Lagrange.† To find

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† Count Joseph Louis Lagrange (1736–1813) the eminent French mathematician, was, in Napoleon's words, 'la haute pyramide des sciences mathématiques'. According to Miss A. M. Clerke his 'treatises are not only storehouses of ingenious methods, but models of symmetrical form. The clearness, elegance, and originality of his mode of presentation give lucidity to what is obscure, novelty to what is familiar, and simplicity to what is abstruse. His genius was one of generalisation and abstraction; and the aspirations of the time towards unity and perfection received, by his serene labours, an embodiment denied to them in the troubled world of politics'. *Encyclopaedia Britannica*, 9th ed. (1889) Edinburgh.

the stationary values of a function like $q(x_1, x_2, x_3)$, subject to a constraint of the form $p(x_1, x_2, x_3) = 0$, a new function is constructed

$$\Phi = q + \lambda p, \tag{10}$$

where λ is called a Lagrangian multiplier. The necessary condition for a maximum or minimum is then that

$$\frac{\partial\Phi}{\partial x_1} = \frac{\partial\Phi}{\partial x_2} = \frac{\partial\Phi}{\partial x_3} = 0,$$

or again more compactly the *three* equations (one for each value of *i*)

$$\frac{\partial\Phi}{\partial x_i} = 0. \tag{11}$$

In the case of our example

$$q(x_1, x_2, x_3) = 2V\Sigma_i\frac{U_i}{x_i}$$

subject to the volume constraint given by the function

$$p(x_1, x_2, x_3) = V - x_1x_2x_3 = 0,$$

or to preserve generality,

$$p = V - x_ix_jx_k, \quad (i, j, k) = (1, 2, 3). \tag{12}$$

Following Lagrange's method a new function is constructed

$$\Phi = 2V\Sigma_i\frac{U_i}{x_i} + \lambda(V - x_ix_jx_k). \tag{13}$$

The necessary condition for a maximum or minimum is then given by the *three* equations

$$\begin{aligned}\frac{\partial\Phi}{\partial x_i} &= -2V\frac{U_i}{x_i^2} - \lambda x_jx_k\\ &= \frac{-V}{x_i^2}(2U_i - \lambda x_i), \quad \text{since } x_jx_k = \frac{V}{x_i}\\ &= 0.\end{aligned} \tag{14}$$

From this the general statement is derived that the *minimum* heat loss occurs when the dimensions of the block are proportional to the mean transmittance values:

$$x_1:x_2:x_3::U_1:U_2:U_3 \tag{15}$$

In this form, the condition is seen to be analogous to Lamy's Theorem, first stated in the seventeenth century, concerning the equilibrium of three forces acting at a point:

If three forces acting at a point are in equilibrium, each force is proportional to the sine of the angle contained between the directions of the other two.

That is to say (Fig. 3.4)

$$X_1:X_2:X_3::\sin\theta_1:\sin\theta_2:\sin\theta_3.$$

This means that three forces in equilibrium may be represented by the sides of a triangle (or that the diagonal of a parallelogram represents the resolution of two forces proportional to its sides). Such a simple theorem continues to guide engineering practice despite the fact that the 'model' point may be a rivetted joint, the forces may act not in two 'model' lines but through two rolled steel joists, and the resultant force may act through a concrete abutment. Furthermore, whatever complicated allowances have to be made to adjust theory to practice, Lamy's Theorem has the overriding merit of being memorable and providing a conceptual context within which forces in engineering structures can be thought about sensibly. No one goes about thinking that three forces at a point will be in equilibrium if they can be represented by the sides of an *equilateral* triangle. Yet in building studies authoritative statements are continually found to the effect that a *cube* is the best form of building to reduce heat losses! If the forces are equal, yes an equilateral triangle: if the transmittance values of all six faces are equal, yes a cube. But how often is that the case?

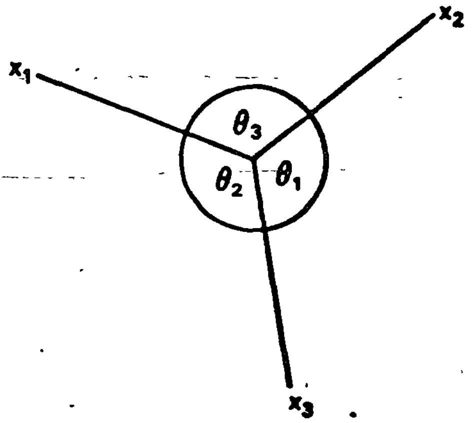

Fig. 3.4

A general and simple theorem may now be stated:

THEOREM 1. *A simple rectangular block of given volume loses the least amount of heat if the dimension of each edge is proportional to the mean thermal transmittance value of the faces defined by the other two edges.*

The fact that no general quantitative statements of this kind about built forms exist suggests how far away is a science of architectural form (artificial morphology?).

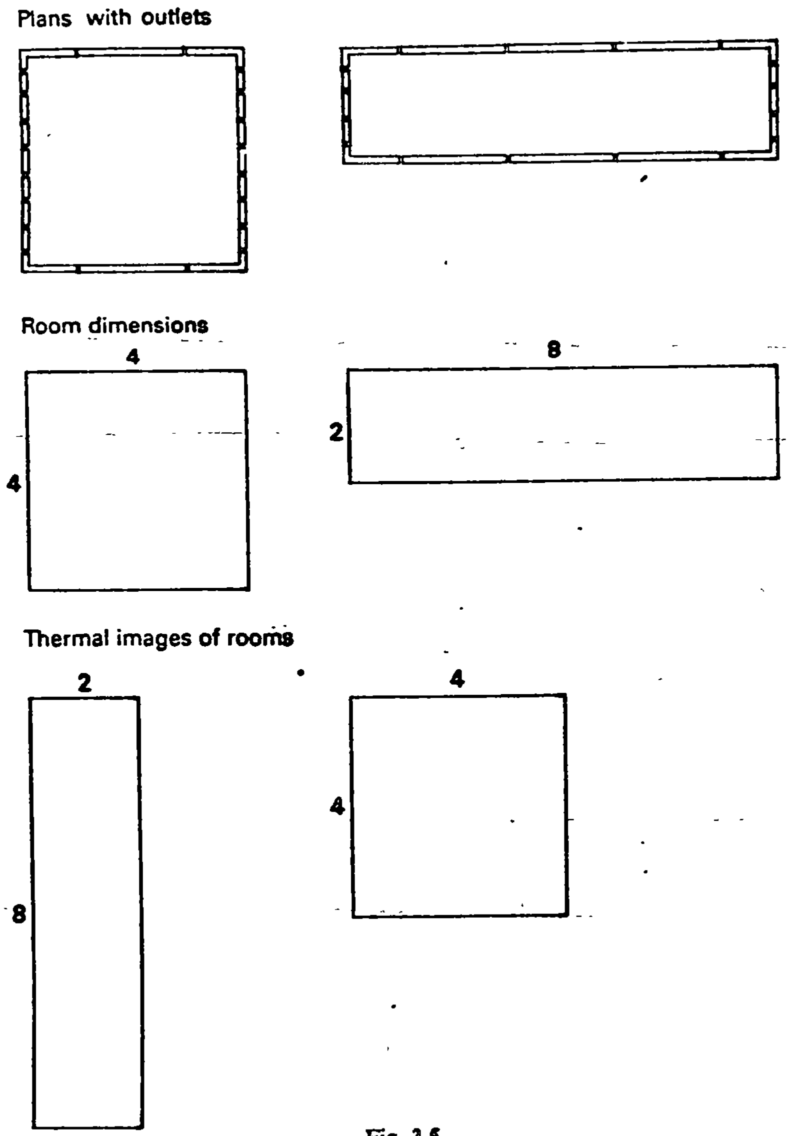

Fig. 3.5

Returning once again to our example, the original assumptions need to be re-examined to see whether they can be improved to give a more realistic picture of the problem. But there is something else that can be done which may increase an appreciation of the intrinsic structure of the problem lost in the analytical approach adopted in solving it. The solution is simple and – as often happens – once its form is seen a very direct way of arriving at it becomes apparent without all the paraphernalia of analytical calculus.

The rectangular parallelepiped with the minimum surface area is a cube. However, if opposite pairs of faces have different mean transmittance values the form which will minimise heat losses – not surface area – is the built form whose *thermal image is a cube* such that heat losses through all three pairs of opposite faces are equal. In our notation above this requires that

$$U_1x_2x_3 = x_1U_2x_3 = x_1x_2U_3, \qquad (16)$$

whence the rule (Equation 15):

$$x_1:x_2:x_3::U_1:U_2:U_3.$$

A 'two-dimensional' example will make this argument clear (Fig. 3.5). Consider a rectangular room with a floor and a ceiling which transmit no heat, and walls which transmit heat only through specific outlets, the number of outlets per unit length of wall is thus proportional to the thermal transmittance value of the wall. One room is square, 4 × 4, and has the minimum overall wall length, 16, for its area, 16. The other room is four times as long as it is wide, 8 × 2, and has a wall length of 20 for the same area, 16. However, the square room has 20 outlets, 4 placed on one pair of opposite walls (low thermal transmission), and 16 on the adjacent pair of opposite walls (high thermal transmission). The heat loss from this room – proportional to the number of outlets – is 20 units. The long rectangular room has the same number of outlets per unit length as the square room along its corresponding walls. Thus the long walls have 8 × (2/4) = 4 outlets each, the short walls 2 × (8/4) = 4 outlets each. Altogether the heat loss is 16 which is less than that of the square room. Now if the thermal images are drawn of these rooms, using the number of outlets per wall as the measure (the total flow of heat through each surface) and not the length of the wall (not the surface area of each face), the pictures are exactly reversed. The 4 × 4 room has an 8 × 2 thermal image, and the 8 × 2 room has a 4 × 4 square, thermal image.† In three dimensions, the thermal image is cubic if heat losses are minimised.

It is thus misleading to suggest that cubic forms, because they minimise surface area with respect to volume, have any particular merits in terms of

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† This, of course, is an example of mapping. See March and Steadman (1971), ch. 1.

heat losses and hence running costs,† or that measures of compactness which compare ratios of surface areas to volumes have any significant relation to thermal performance.‡ If they have, it is pure chance and probably the fortuitous outcome of a combination of factors including the somewhat conflicting tendencies of construction costs and maintenance.

A. C. Hardy and P. E. O'Sullivan (1967) have argued for deeper office buildings which rely on artificial lighting and air-conditioning. As F. D. Holister (1967) has pointed out there are many good reasons to support this view. But what shape of block, according to our model, and on thermal considerations alone, might deep-planning lead to? It can be shown, if one of the dimensions in the general example above is fixed, $x_1 = X_1$ say, that

$$\frac{x_2}{U_2} = \frac{x_3}{U_3} = \left(\frac{V}{X_1 U_2 U_3}\right)^{\frac{1}{2}} \tag{17}$$

for minimum heat loss. Hardy (1966) gives the following values of X_1: for daylighting, a building width of 14 m; for permanent supplementary artificial lighting of interiors (PSALI), a width of 22.5 m; and for permanent artificial lighting (PAL), a width of 27 m. For simplicity the first can be called, 4 units wide; the second, 6; and the third, 8. Consider now a building whose volume is 288 cubic units, with $U_2 = 2$ and $U_3 = 1$ in the appropriate units. Especially note that the mean thermal transmittance of the faces of the building at right-angles to the depth X_1, that is to say the principal window walls in an office block, has no effect on the optimum shape of the built form.

(*a*) With daylighting:

$$X_1 = 4; x_2 = 2\left(\frac{288}{4.1.2}\right)^{\frac{1}{2}} = 12; x_3 = \frac{x_2}{2} = 6.$$

(*b*) With PSALI:

$$X_1 = 6; x_2 = 2\left(\frac{288}{6.1.2}\right)^{\frac{1}{2}} \doteq 10;\S\ x_3 = \frac{x_2}{2} = 5.$$

(*c*) With PAL:

$$X_1 = 8; x_2 = 2\left(\frac{288}{8.1.2}\right)^{\frac{1}{2}} \doteq 8;\S\ x_3 = \frac{x_2}{2} = 4.$$

Fig. 3.6 shows the shapes that the built forms take to minimise heat

losses. The clear trend – as can be seen algebraically from Equation 17 above – is for both length (x_2) and height (x_3) to decrease with increasing width (X_1). This is true whatever constant values of U_2, U_3 and V are chosen for the comparative exercise. However, while particular values of these independent variables might lead to buildings which use artificial lighting being 'more cube like' (Hardy 1966), in *general* there is no justification for this statement. Thus, within the limitations of our model, the only general remark that can be made is that blocks of similar construction† would need, as planning became deeper, to be both lower and shorter if heat losses were to be minimised.

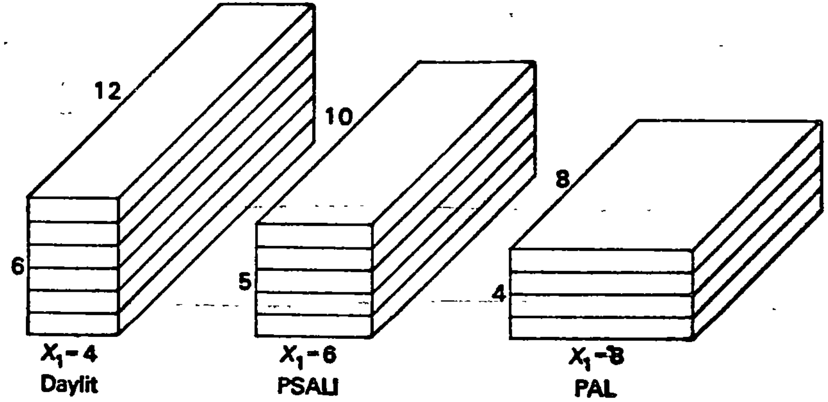

Fig. 3.6

Example two

What shape should a building be to reduce its cost?

Once again some crude simplifications must initially be made with only rectangular, block-like forms considered. And, to start with, the discussion will be limited merely to the cost of the external envelope, including the groundworks, of the form. Suppose that consideration includes a range of shapes to accommodate the same floor area, which for a given floor-to-ceiling height will produce a constant volume. The discussion will continue, as above, to treat height as a continuous variable although in practice it will be step-like depending on the number of floors.

The argument for costs follows the same lines as that for thermal performance. Let the dimensions of the block be x_1, x_2 and x_3 as before. Let C_1 be the mean cost, $\frac{1}{2}(C_{11} + C_{12})$, of the two faces with dimensions x_2 and

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† See, for example Hardy (1966).

‡ For such a measure see T. A. Markus *et al.* (1970).

§ To nearest whole number for the purposes of illustration.

† Excepting the principal walls whose manner of construction does not affect shape, but does modify thermal performance.

x_3 respectively, and let C_2 and C_3† be similarly defined. Then the least cost solution is given by

$$x_1:x_2:x_3::C_1:C_2:C_3 \tag{18}$$

with each x_i given by

$$x_i = C_i\left(\frac{V}{C_1C_2C_3}\right)^{1/3}. \tag{19}$$

Thus another theorem may be stated:

THEOREM 2. *The envelope of a simple rectangular block of given volume has a minimum cost when the dimension of each edge is proportional to the mean cost of the faces defined by the other two.*

The form of this theorem is the same as Theorem 1 above. Within the limiting simplifications of our assumptions it implies that buildings which are cube-like or which minimise surface area are not in general less costly to build. It is the *cost image* which matters, not the physical form of the building; and it is when the *cost image is a cube* that costs are least. An example will make this clear. Consider the four cost situations given (Table A) for a block with a volume of 216 units.

TABLE A

Situation	Ratio of costs C_1: C_2: C_3	Note
(*a*)	1:3 :9	Extremely expensive foundations, or high land costs
(*b*)	1:1.5 :2.25	
(*c*)	1:1 :1	
(*d*)	1:0.5 :0.25	Low cost roofing and ground slab, or low land costs

TABLE B

Situation	Dimensions of block x_1	x_2	x_3	Total surface area	Surface area less ground slab area
(*a*)	2	6	18	312	300
(*b*)	4	6	9	228	204
(*c*)	6	6	6	216	180
(*d*)	12	6	3	252	189

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† C_3 includes C_{13}, the cost of the foundations and slab *less* the cost of the groundfloor at the same rate as the suspended floors, and C_{12}, the cost of the roof *less* the cost of the ceiling.

Using formula 19 the dimensions in Table B are derived for the least cost solution in each situation (Fig. 3.7):

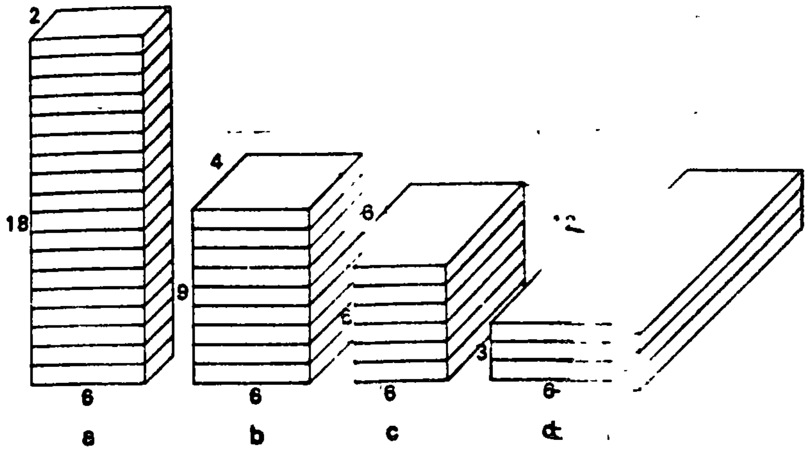

Fig. 3.7

There are a number of points that might be made about this example. Firstly, the possibility has been introduced that the cost of the building may be influenced by land costs. The discussion can return later to the study of the way in which different built forms 'use' land. Secondly, it should be noted that, although in the context of this particular example the cubic form (*c*) does have the least surface area, there are two forms which have the least exposed surface area. One of these is the cubic form, but the other is the squatter, spread-out form (*d*). If maintenance costs were, for example, directly proportional to the exposed surface area then as in Example 1 it would be clear that the half-cube is the best form to minimise these costs. Thirdly, it is important to remember that only the 'envelope' costs have been considered and no costs which arise because of the form, for example, the provision of lifts and staircases in tall buildings and air-conditioning in deep buildings. Fourthly, the 'envelope' costs are part of the capital cost of a building which in itself may be a fraction of the total cost of the building in use (Stone 1967). In fact, the cost of the envelope may not account for much more than about 10% of the capital cost.

To investigate the relationship between cost and form more deeply it will be necessary to construct more complex models as suggested by Bullock, Dickens and Steadman (19[illegible]):

> If...we could cost the *range of buildings* obtained by a systematic transformation of the overall form..., it would be possible, in theory, to plot the cost of all different possible variations of the factors that have been isolated. If carried out on a sufficiently large

> number of examples, our understanding of which elements are most significant from the cost point of view would be considerably enlarged. In the first place changes in the factors controlling the cost of individual elements and of the whole building could be systematically explored. And in the second place this would make possible more accurate *forecasts* of the results of design decision, without requiring the architect to produce detailed designs for every variation. (See also Harper 1968.)

These authors illustrate this approach for two building types, a science teaching block and a residential building. Our simple model illustrates what these authors call 'a systematic transformation of the overall form'. Essentially, they propose a volume-preserving, three-way stretch transformation, or mapping, of the form

$$M:\begin{bmatrix}x_1\\x_2\\x_3\end{bmatrix}\rightarrow\begin{bmatrix}a_{11} & . & .\\ . & a_{22} & .\\ . & . & a_{33}\end{bmatrix}\begin{bmatrix}x_1\\x_2\\x_3\end{bmatrix}. \tag{20}$$

where, to preserve volume, $a_{11}a_{22}a_{33} = 1$. The scalar matrix $[a_{ij}\delta_{ij}]$, where δ_{ij} is the Kronecker delta so that $\delta_{ij} = 0$, $i \neq j$, and $\delta_{ij} = 1$, $i = j$, may be compared to the symmetric *tensor* of rank two in a principal axis transformation. With this in mind we may think of the built form experiencing orthogonal *strain* under orthogonal *stress* represented by such a tensor.[†] They then compare relative costs of the elements, in each transformation, per unit area of floor space. Now, if in our model the storey height is h the simple expression results:

$$V = Ah, \tag{21}$$

where A is the total floor area of the form. However, $V = x_i x_j x_k$ and the cost of each opposite pair of faces of the block is given by $C_i x_j x_k$, so that if K_i is the cost of these faces per unit area of floorspace the following may be expressed:

$$\begin{aligned} K_i &= \frac{C_i x_j x_k}{A} \\ &= \frac{C_i x_j x_k h}{x_i x_j x_k} \\ &= \frac{C_i h}{x_i}. \end{aligned} \tag{22}$$

[†] This mechanistic analogy is related, as Philip Steadman has reminded me, to the work of the biologist D'Arcy Thompson (1917) which in its turn made use of H. de Parsons (1888) and Selig Hecht (1912). This early work was mainly descriptive with little explanatory power, but recently Robert Rosen has indicated a more functional approach (1967).

From this our previous condition (Equation 18) for the optimum (least) cost of envelope reduces to the simple rule:

$$K_1 = K_2 = K_3 \tag{23}$$

and

THEOREM 3. *The envelope of a simple rectangular block of given volume and floor area has least cost when the costs per unit area of floorspace of the pairs of opposite faces are equal.*

In the case of the study by Bullock, Dickens and Steadman of a university teaching block, they found

> rather surprisingly perhaps, from this limited examination that other factors being equal, the *form* of the building – even allowing for the necessary variations in gross area – does not as such have an important effect on *capital* cost: although it might considerably affect the running costs. The cost of heating a tall thin building, or the costs of ventilation and lighting in a deep section building might be very significant. The variation in the cost of the particular elements that we have studied – the structure and the lifts – has more effect in some cases on the total capital cost than changes in the building form.[†]

On that note our naive study of built form and cost must be left and our attention turned to another problem.

Example three

How should buildings be laid out in order to make good use of land? Again the question is vague and raises many other questions. In 1930, at the third meeting of Les Congrès Internationaux D'Architecture Moderne in Brussels, Walter Gropius addressed himself to this problem as it related to housing in a paper entitled 'Flach-, mittel- oder hochbau?'.[‡] In this paper, among other things, Gropius attempted to demonstrate certain relationships existing between building height, open space, sunlighting, and orientation. He developed Heiligenthal's rule-of-thumb[§] that the dis-

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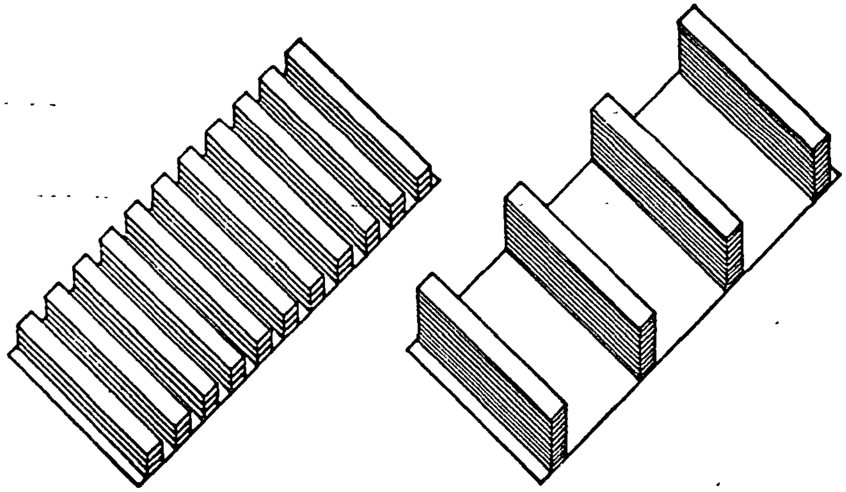
[†] Bullock, Dickens & Steadman (1968), p. 169. They go on to demonstrate that the most significant factor is a variation in floor area and, as this is determined by the way in which the building is used, that a study of 'activity patterns' would seem worthwhile in order to develop a more comprehensive model. Such a model, of course, can no longer be manipulated by ordinary mathematical methods and requires automatic computation.

[‡] Walter Gropius (1931), also translated as 'Houses, walk-ups or apartment blocks' in Gropius (1956). This paper should be compared with George B. Ford's contemporary Harvard City Planning Study (1931).

[§] This rule (according to Kenneth Frampton, 'Notes on Soviet urbanism, 1917–32', in Lewis 1968) was 'categorically applied in all finally approved town plans during the period 1930–32' in the Soviet Union. For recent Soviet work on this problem see the review by V. G. Davidovich, 'Interdependence between height of buildings, density of population and size of towns and settlements' in Davidovich 1968.

tance between parallel blocks must be one-and-a-half times the building height in the case of blocks orientated north–south and two-and-a-half times in the case of blocks orientated east–west – a rule which favoured the north–south orientation in regard to efficiency of land use. On this kind of principle Gropius proposed the following rules for parallel blocks with north–south orientation having from two to ten storeys on a given site:

> 1. Assuming a site of given size and a given angle of sunlighting incidence (30°), i.e. a given illumination condition, the number of beds increases with the number of stories.
> 2. Assuming a given angle of sunlight incidence and distributing a given number of beds (15 sq. m or 161 sq. ft of area of bed) into parallel apartment blocks with varying numbers of stories, the size of the required site decreases with increasing number of stories.
> 3. Assuming a building site of given size and a given number of beds and varying the number of stories, the angle of sunlight incidence decreases with increasing number floors, i.e., the conditions of illumination improve with increased height. (Gropius 1956.)



3 - storey **10 - storey**

Fig. 3.8

These rules were used to counter the contemporary legislation which imposed 'limits on building height instead of dwelling area of building volume' thus depriving 'the public of these obvious economic and hygienic advantages'.

The diagrams which Gropius used to illustrate his assertions (Fig. 3.8) became powerful images of a future and better environment.† In the late

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† However, Le Corbusier was not convinced: 'When in the period before Hitler, the Germans wanted to build according to the laws of the sun...they set up an order which was systematically sterile: corridors, tedious, monotonous parallelism, and silhouettes against the sky that were poverty stricken and unbalanced' (Le Corbusier 1939).

thirties progressive planning schemes were being built on these principles, while, following the Second World War, many official reconstruction schemes throughout Europe were designed this way in accordance with new legislation framed around Gropius' rules, or variations of these. In England, a paper by H. E. Beckett (1942), an illuminating engineer, developed Gropius' work and was finally published in 1942 at a time when fundamental rethinking was going on in relation to post-war planning policies.†

As a first step it is necessary to formalise Gropius' model. The dependent variables are, in turn, the number of beds, the size of the site and the angle of sunlight. We specify the following:

y_1 = number of beds,
y_2 = area of site,
y_3 = tangent of the angle of sunlight.

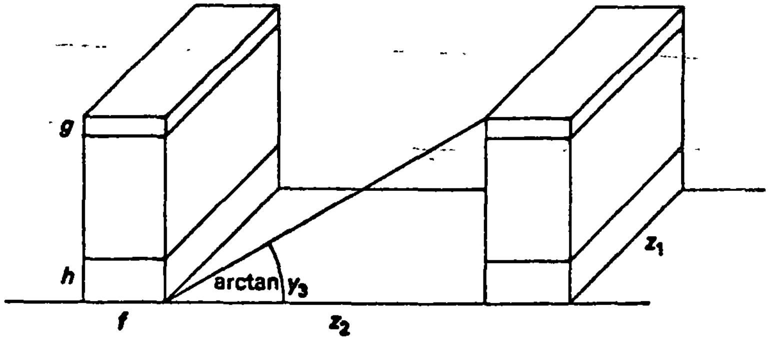

Fig. 3.9

In each rule *one* of these variables is the dependent variable, while the others are given.

The remaining variables are (Fig. 3.9):
z = number of floors
z_1 = length of block,
z_2 = space between blocks,
f = width of block (assumed to be given),
h = storey height (assumed to be given),
g = parapet height (assumed to be given),
β = number of beds per unit floor area (assumed to be a given ratio),

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† This paper is referred to in W. Allen and D. Crompton (1947), which set out the general principles upon which post-war legislation and planning practice in England and Wales was based.

and the principal *independent* variable is

$$x = \text{number of storeys},$$

which can be assumed to be continuous, although only integral values have any architectural meaning in practice. Each of Gropius' rules may then be derived from the behaviour of a function:

$$y_i = \phi_i(x, y_j, y_k) = \phi_i(x), \tag{24}$$

where the variable y_i is found in terms of a function of x, the number of storeys, and given values of the other two variables y_j and y_k. The rules simply state whether y_i increases or decreases with increasing values of x. The first derivative $\mathrm{d}y_i/\mathrm{d}x$ or $\phi'_i(x)$ can be inspected to find out which relationship holds, if any at all.

Our task now in 'building' this Heiligenthal–Gropius model is to establish the functions ϕ_i. By definition, and from the geometry of the forms, three equations relating the variables may be written down:

the number of beds is given by $y_1 = \beta f z_1 x,$ (25)

the site area is given by $y_2 = z_1(f+z_2),$ (26)

and the tangent of the angle of sunlight by $y_3 = \dfrac{hx+g}{z_2}.$ (27)

Using these three equations, and by eliminating z_1 and z_2 from them, the required functions ϕ_i are obtained. For example,

$$y_1 = \beta f z_1 x,$$

but from (27) $z_2 = \dfrac{hx+g}{y_3},$

and from (26) $z_1 = \dfrac{y_2}{f+z_2}$

$$= \frac{y_2 y_3}{hx+fy_3+g}.$$

Hence, $y_1 = \beta f y_2 y_3 \dfrac{x}{hx+fy_3+g},$

or by multiplying up,

$$(hy_1 - \beta f y_2 y_3)x + fy_1 y_3 + gy_1 = 0. \tag{28}$$

From this equation the three required functions are derived, namely,

$$y_1 = \phi_1(x) = \beta f y_2 y_3 \cdot \frac{x}{hx+fy_3+g}, \text{ as above,} \tag{29}$$

$$y_2 = \phi_2(x) = \frac{y_1}{\beta f y_3} \cdot \frac{hx+fy_3+g}{x}, \tag{30}$$

and

$$y_3 = \phi_3(x) = \frac{y_1}{f}\,\frac{hx+g}{\beta y_2 x - y_1}. \tag{31}$$

The first derivatives are obtained in the usual way,†

$$\frac{\mathrm{d}y_1}{\mathrm{d}x} = \phi'_1(x) = \beta f y_2 y_3 \cdot \frac{fy_3+g}{(hx+fy_3+g)^2} > 0, \tag{32}$$

$$\frac{\mathrm{d}y_2}{\mathrm{d}x} = \phi'_2(x) = \frac{-y_1}{\beta f y_3} \cdot \frac{fy_3+g}{x^2} \qquad < 0, \tag{33}$$

$$\frac{\mathrm{d}y_3}{\mathrm{d}x} = \phi'_3(x) = \frac{-y_1}{f} \cdot \frac{hy_1+\beta g y_2}{(\beta y_2 x - y_1)^2} \qquad < 0. \tag{34}$$

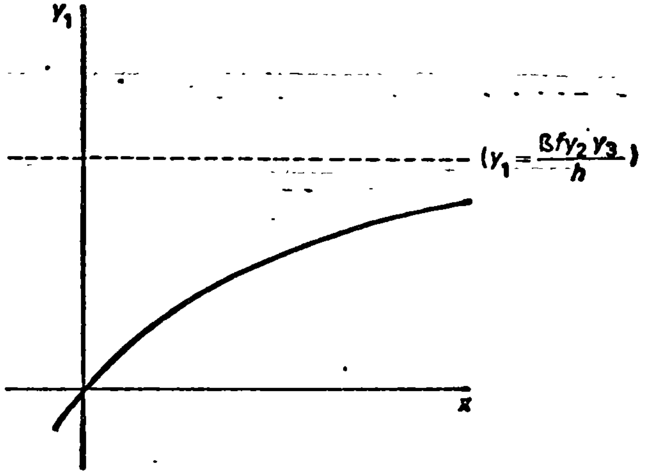

Fig. 3.10

Equations 32, 33 and 34 are true for all the positive values of the variables that are our concern. The first confirms that bed spaces *increase* with the number of storeys, the second that the site area required *decreases* with increasing storeys, and the last that the angle of obstruction *lessens* as the blocks increase in height (always assuming that in each case the other 'variables' are held constant).

Each function may be plotted graphically (Figs. 3.10, 3.11, 3.12). In fact each function may be represented by a hyperbola.‡ (Only that part of the

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† See any standard work on differential calculus, or Montgomery and Jones (1970), p. 132.

‡ See any standard work on analytical geometry.

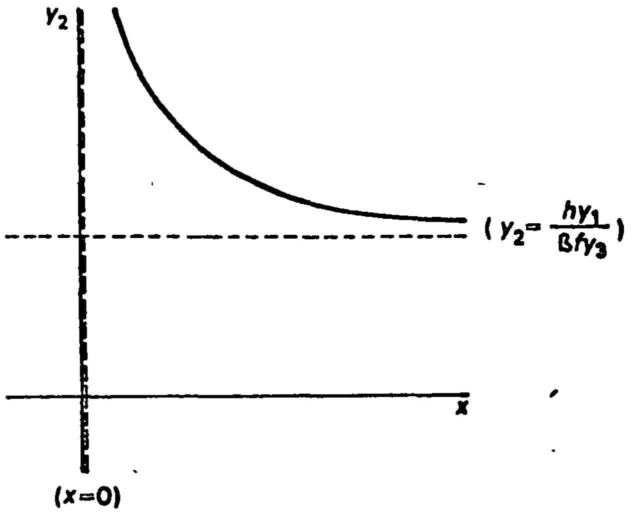

Fig. 3.11

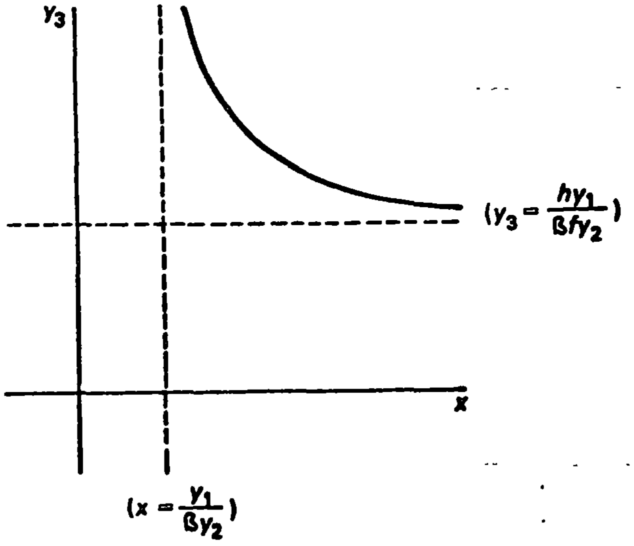

Fig. 3.12

curve which lies within the positive quadrant, of course, is of interest.) The horizontal asymptotes set limits on extreme values of the y_i as x becomes very large. They are then related by the equation

$$hy_1 - \beta f y_2 y_3 = 0, \quad \text{for } x \to \infty. \tag{35}$$

This may surprise the unwary. It means for example that, with this form

of development, there is an upper limit on density no matter how high the project is built. To take a specific example: if the bed space ratio is one bed to 15 sq. m of the gross floor area then $\beta = \frac{1}{15}$, if the block width is 9 m then $f = 9$, if the storey height is 3 m then $h = 3$, and if the angle of obstruction has a tangent value of $\frac{2}{3}$ then $y_3 = \frac{2}{3}$ (Heiligenthal's rule of thumb for north–south orientation). The density of bed spaces per *hectare*[†] is then given by

$$\frac{y_1}{y_2} = \frac{\beta f y_3}{h}.10{,}000 \tag{36}$$

$$= \frac{9.2}{15.3.3}.10{,}000$$

$$= 1333.$$

Thus with these values (close to Gropius' recommendations for 'hygienic' dwellings) the maximum possible density that could be achieved *no matter how high we built* is 1333 bed spaces per hectare, or about 533 persons per acre. Higher densities than these, using parallel blocks, could be achieved only if less space were allocated to every bed, or if the building depth were increased (perhaps windowless rooms as the old railroad tenements in New York used to have[‡]), or by diminishing the amount of light reaching the facade of the building, or by reducing ceiling heights. Each of these measured would be detrimental to housing quality and below acceptable standards.[§]

Another point to notice is that although the number of bed spaces does increase with building height (Fig. 3.10), the *rate* at which it does so *decreases* quite rapidly. This is to be seen from the second derivative

$$\phi_1''(x) = \frac{-\beta f h y_2 y_3 (f y_3 + g)}{(hx + f y_3 + g)^3} < 0, \tag{37}$$

which demonstrates that the order of the rate of increase of density with height changes (decreases) inversely with the cube of x. By far the greatest gains in density are to be made with the lower number of storeys, from one to six, say. The returns beyond this diminish very rapidly indeed. For

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[†] 1 hectare equals 10,000 sq. m or 2.47 acres: roughly, 4 hectares equal 10 acres.

[‡] These tenements were approximately 22.5 m deep with eight out of twelve of the rooms on each floor with no windows. In 1894, New York's worst ward had a density of 986.4 persons per acre. See Gray (1947).

[§] Note that with the angle of obstruction employed in British planning controls for this kind of development (daylight indicator D1), the value of y_3 is approximately $\frac{1}{2}$. This means that the maximum density of bed spaces per hectare with these values of β, f and h is reduced to 1000, or 400 persons per acre.

example, using the values of β, f, h, y_3 above, and setting the parapet height to zero for simplicity so that $g = 0$, from Equation 29 the following can be derived:

$$\frac{y_1}{y_2} = \beta f y_3 . \frac{x}{hx+fy_3+g} \tag{38}$$

$$= \frac{9.2}{15.3} . \frac{x}{3x+9.2/3} .10{,}000 \text{ (beds per hectare)}$$

$$= \frac{x}{x+2} .1333.$$

The ratio $x/(x+2)$ is thus the *proportion* of the limiting density (1333 beds per hectare) achieved at x storeys. The table below shows values for various storey heights:

	No. of storeys				
	1	2	3	4	6
Proportion of limiting density	33%	50%	60%	67%	75%
Density per hectare	444	667	800	888	1000
Density per acre	178	267	320	355	400

Note the extremely high densities achieved with even 1- and 2-storey blocks: this is because of oversimplifications in the model. The Heiligenthal–Gropius model does not allow for other residential land uses such as roads and parking areas which become critical with low-rise high-density housing, nor are any constraints, other than the obstruction angle, placed on how close the blocks can be to one another to ensure, for example, fire protection and adequate privacy (Croghan and Hawkes 1970). Nevertheless the simplicity of the model does demonstrate the 'structural' properties of the relationships within the limits of the assumptions. Gropius used his model polemically to demonstrate the advantages of *hochbau*, 10- to 12-storey apartments, but a more discerning appreciation of its 'structure' might have convinced him that the greatest gains were to be found in *flachbau*, low-rise housing.† Before discussing Beckett's modifications of this model it is perhaps worth stating formally three theorems concerning the land use performance of simple rectangular blocks, or built forms, arranged in parallel rows as defined above. Note that these theorems are a little more general than Gropius' original rules: they are not dependent on particular values of the angle of obstruction, or particular values of the bed density β (in fact since the number of bed spaces is directly proportional, in the model, to the total floor area we shall use the latter instead). We also add corollaries.

The Heiligenthal–Gropius theorems

THEOREM 4. *Assuming a rectangular site of given size and given a fixed angle of obstruction between parallel and equal built forms, the total floor area increases hyperbolically with the number of storeys.*

Corollary. *The order of the rate of change of this increase varies inversely to the square of the number of storeys, the floor area asymptotically approaching an upper limit given by the products of the ratio of building width to storey height, the site area and the tangent of the angle of obstruction.*

THEOREM 5. *Assuming a given angle of obstruction between parallel and equal built forms and a constant floor area to be distributed within these forms, the size of the required site diminishes hyperbolically with the number of storeys.*

Corollary. *The order of the rate of change of this decrease varies inversely to the square of the number of storeys, the site area asymptotically approaching a lower limit given by the product of the ratio of storey height to building width, floor area and cotangent of the angle of obstruction.*

THEOREM 6. *Assuming a rectangular site of given size and constant floor area distributed within equal and parallel built forms, the angle of obstruction decreases hyperbolically with increasing number of storeys.*

Corollary. *The order of the rate of change of this decrease varies inversely to the square of the number of storeys, the tangent of the angle asymptotically approaching a lower limit given by the product of storey height to building width, and the ratio of the floor area to site area (floorspace index).*

Beckett's paper 'Population Density and the Heights of Buildings' (1942) was the first attempt, to the author's knowledge, to apply the formal apparatus of mathematical modelling to land use and built form problems. The paper's summary reads:

> Although it is nowadays generally accepted that, for a given population density, rehousing in higher and more widely spaced buildings is likely to result in improved natural lighting conditions, ideas have hitherto remained somewhat vague.
>
> In the present paper the truth of the above statement for the special case of tenement blocks arranged in parallel rows, is established by a simple mathematical analysis. It is shown that, except in very open developments such as are rarely encountered in towns, an increase in the height of the buildings will, for a given population density, always improve the lighting conditions, or, less desirably, that more people can by this means be

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† For forty years, modern planning and architectural practice has been influenced by the Gropius doctrine. Only recently have designers returned to a serious consideration of low-rise high-density housing: not on the whole, however, for intrinsic geometrical reasons, but out of sociological concern. Nevertheless, two critics in England have persistently pointed at the geometrical weaknesses in the high-rise doctrine: see A. T. Edwards (1968) and W. Segal (1964). See also Davidovich (1968), pp. 68–9, who on the basis of a more comprehensive model states: 'it can be concluded that there is no economic justification for planning buildings over five stories high...There is no justification for skyscrapers in a socialist society. The high cost of land, the concentration of capital and commercial life and the hunger for publicity – these factors have caused the erection of skyscrapers in the cities of the USA.'

housed on a given site without making the lighting worse. In the latter case it can frequently happen that the increase in population density is accompanied by an *increase* in the amount of open space per person.

The analysis rests on the assumption that, for a given orientation of the blocks, the lighting conditions are defined by the angle of obstruction (determined by its tangent [y_3, in the above notation] at the ground-floor windows). The latter part of the note is concerned with an examination of the amounts of daylight and sunshine which can be received with various values of y_3.

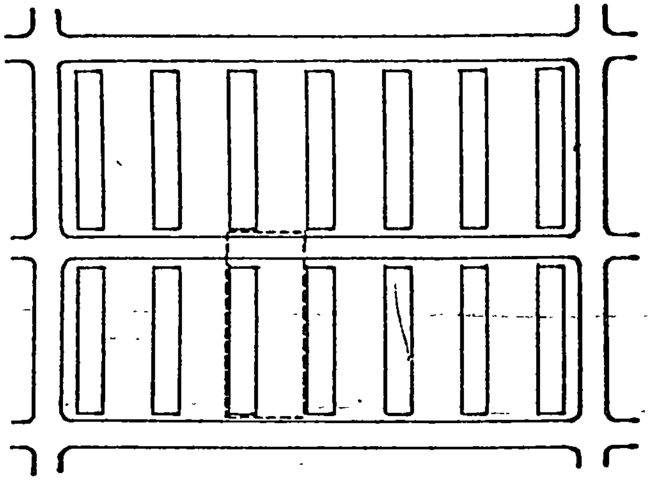

Fig. 3.13

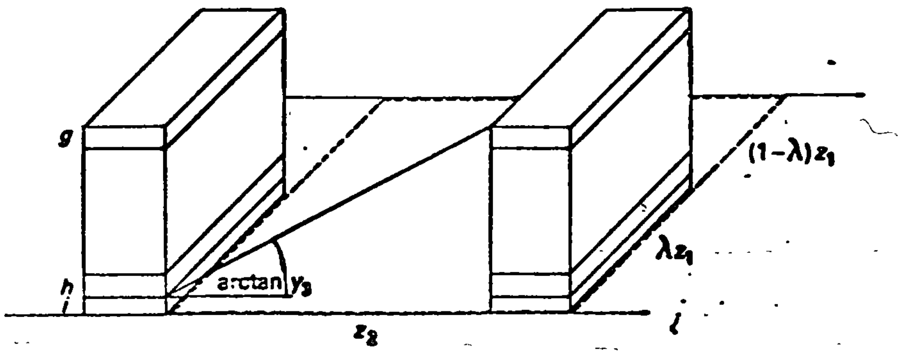

Fig. 3.14

Beckett's model considers equal rectangular blocks arranged in parallel rows with intersecting streets (Fig. 3.13). The intersection of streets is a refinement on the Heiligenthal–Gropius model. Beckett's own section through the blocks differs in one small, but significant, way from the previous model (Fig. 3.9). Instead of a parapet at roof level, there is, as it were, a 'negative parapet' at ground level: the angle of obstruction is read from a point above the ground on the façade of the first floor. The Heiligenthal–Gropius section can be used with the parapet, but the equations to measure the angle of obstruction should be modified in the way proposed by Beckett (Fig. 3.14). In plan, let z_1 be the length of the 'unit' site and define the length of the block as a proportion, λ, of this.

The variables may be listed

z_1 = length of site,
z_2 = distance between blocks,
f = width of block,
h = storey height,
g = parapet height,
i = height at which the angle of obstruction intersects the façade ($0<i<h$),
β = number of beds (persons, etc.)† per unit floor area,
λ = proportion of site length to given block length;
thus λz_1 = length of block,
$(1-\lambda)z_1$ = longitudinal space between blocks;
and x = number of storeys,
y_1 = number of beds (persons, etc.),‡
y_2 = site area,
y_3 = tangent of the angle of obstruction,
y_4 = area of open space.

The principal dependent variables studied by Beckett are

$u_1 = y_1/y_2$ = bed space (population, etc.)‡ density in relation to site area,
$u_2 = y_4/y_2$ = open space index,
$u_3 = u_1/u_2$ = bed space (population, etc.)‡ density in relation to open space.

As before the relationships between these variables are established by definition and from the geometry of the layout.

For the number of bed spaces (persons, etc.), $y_1 = \beta\lambda f z_1 x$, (39)

---

† The 'dimension' of β determines the meaning of y_1, u_1 and u_3. Thus, if it is a measure of bedspaces per unit floor area, then y_1 is the number of bedspaces (as studied by Gropius); if it is a measure of population per unit floor area, then y_1 is the number of people, u_1 is the site density and u_3 is the number of persons to a unit area of open space (as studied by Beckett); if, however, it is set equal to 1 simply as a number, then y_1 is the area of floor space and u_1 is the floorspace index (Beckett's measure). Leaving the meaning of β open like this allows us to interpret the model in a variety of ways.

‡ See preceding footnote.

for the site area, $$y_2 = z_1(f+z_2), \quad (40)$$

for the tangent of the angle of obstruction, $$y_3 = \frac{hx+g-i}{z_2}, \quad (41)$$

and for the area of open space, $$y_4 = y_2 - \frac{y_1}{\beta x}. \quad (42)$$

The equation which relates y_1, y_2 and y_3 is found by eliminating z_1 and z_2 as before. This gives

$$(hy_1 - \beta\lambda f y_2 y_3)x + (fy_3+g-i)y_1 = 0 \quad (43)$$

which may be compared with Equation 28. The Heiligenthal–Gropius model is seen to be a special case of this Beckett model for the values $\lambda = 1$ (the blocks are continuous) and $i = 0$ (the obstruction angle is measured at the point where the building and ground meet). Beckett's equations follow:†

$$u_1 = \psi_1(x) = \beta\lambda f y_3 \cdot \frac{x}{hx+fy_3+g-i}, \quad (44)$$

$$u_2 = \psi_2(x) = 1 - \frac{\lambda f y_3}{hx+fy_3+g-i}, \text{ with varying } u_1, \quad (45)$$

$$= 1 - \frac{u_1}{\beta x}, \text{ with varying } y_3,$$

$$u_3 = \psi_3(x) = \beta\lambda f y_3 \cdot \frac{x}{hx+(1-\lambda)fy_3+g-i},\ddagger \text{ with varying } u_1, \quad (46)$$

$$= \frac{\beta u_1 x}{\beta x - u_1}, \text{ with varying } y_3$$

and $$y_3 = \phi_3(x) = \frac{u_1}{f} \cdot \frac{hx+g-i}{\beta\lambda x - u_1}. \quad (47)$$

The behaviour of $\psi_2(x)$ and $\psi_3(x)$ may be investigated in terms of either u_1 or y_3. Again the functions may be plotted graphically as hyperbolae (Figs. 3.15, 3.16, 3.17, 3.18 show original graphs worked out by Beckett for specific values of the independent variables: $g = 0$, $f = 3h$, $i = 0.6h$, $\lambda = 0.75$). In some cases the behaviour of the functions is not so predictable: for example, under some conditions $\psi_1(x)$ increases with the number of storeys, but under other conditions the function decreases.

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† Our own notation differs from Beckett's.

‡ Beckett, in fact, studied the behaviour of u_3^{-1}, the amount of open space per person.

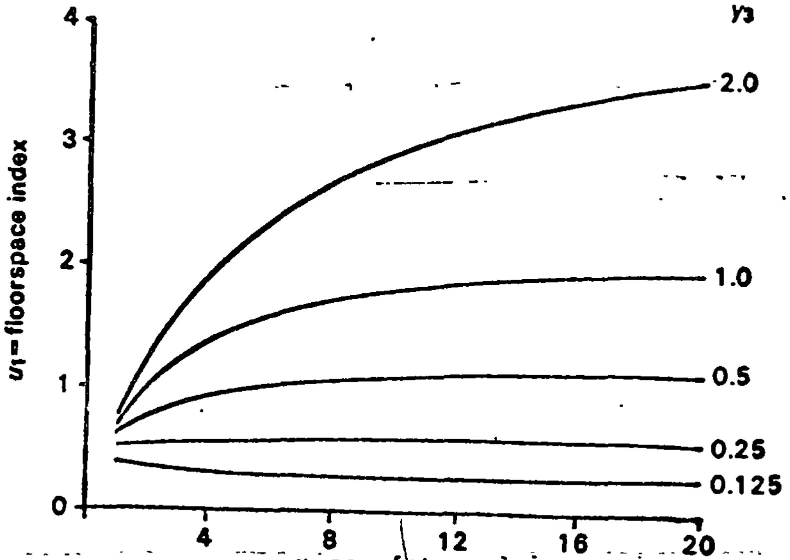

Fig. 3.15

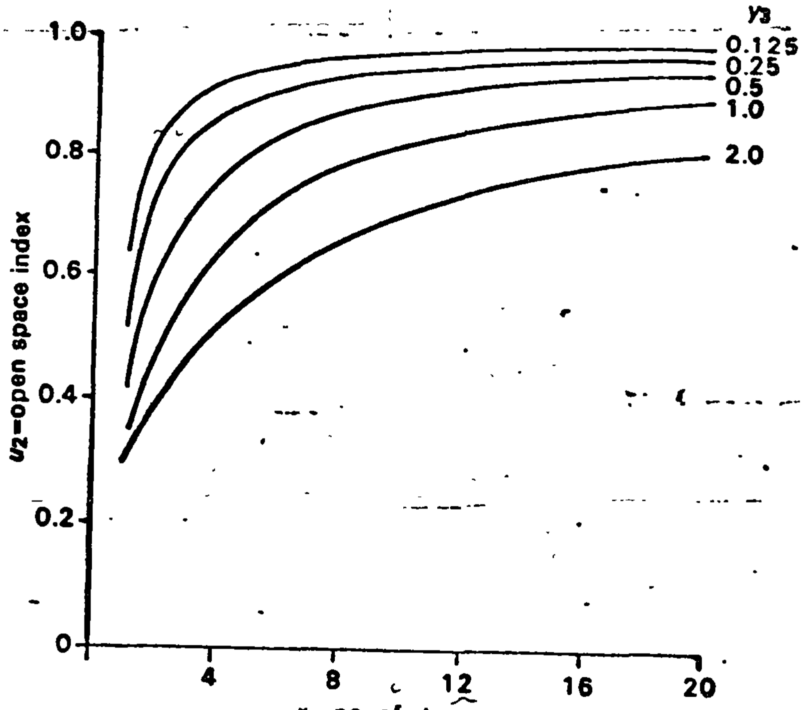

Fig. 3.16

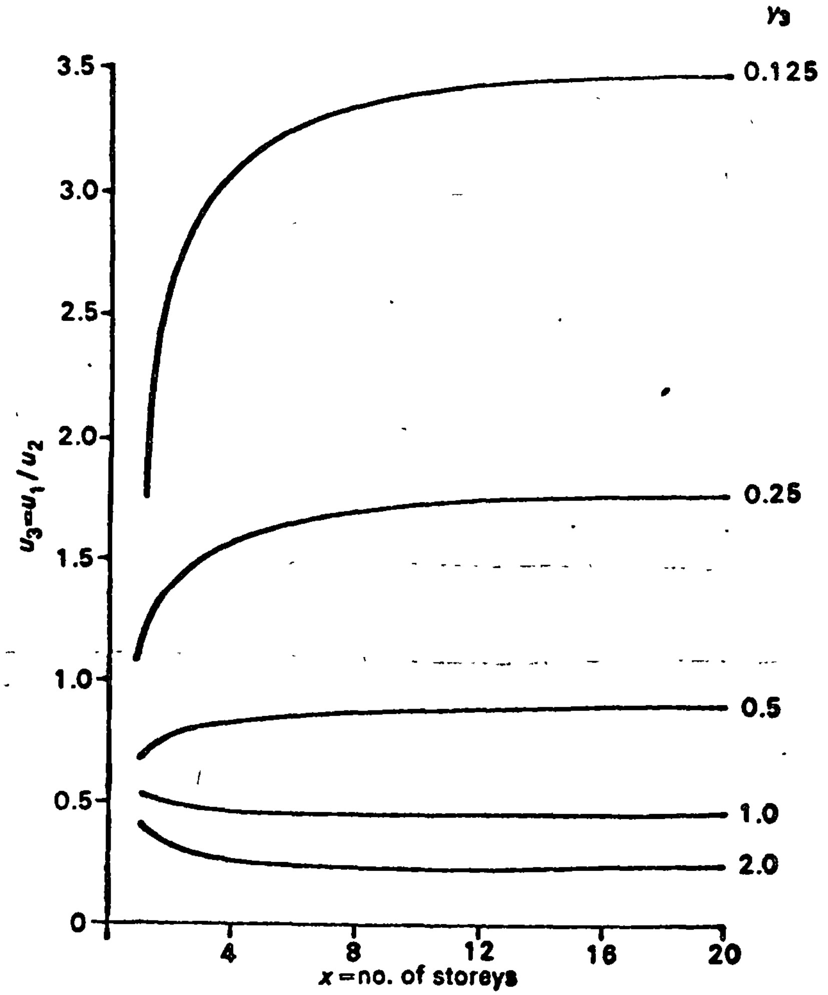

Fig. 3.17

This difference from the Heiligenthal–Gropius model is *entirely* due to the decision to measure the angle of obstruction at a point above the ground level. This is why the change from one model to the other 'is small, but significant'.

Once again the functions tend to finite limits as the number of storeys increase, but whether the function approaches this limit from above or below depends on the value of the derivative. Thus

$$\text{for } \psi_1(x),\ \frac{\mathrm{d}u_1}{\mathrm{d}x} = \psi_1'(x) = \beta\lambda f y_3 \cdot \frac{(fy_3+g-i)}{(hx+fy_3+g-i)^2}, \tag{48}$$

and $\psi_1'(x)$ is greater than, equal to, or less than ($>$, $=$, or $<$) according to whether $fy_3+g-i>, =,$ or <0; that is, whether $y_3>, =,$ or $<(i-g)/f$. The behaviour of the function depends then on the relationship between f, g and i. Note that with $i = 0$, the unequivocal Gropius rule is reconstructed that the floor space increases with the number of storeys. In any case $\psi_1(x)$ approaches a limit as the number of storeys becomes very large:

$$\lim_{x\to\infty} \psi_1(x) = \frac{\beta\lambda f y_3}{h}. \tag{49}$$

With β set to 1 this means that the limiting floorspace index is $\lambda f y_3/h$, or approximately 1.12 when $\lambda = 0.75$, $f = 3h$ and $y_3 = 0.5$, that is when

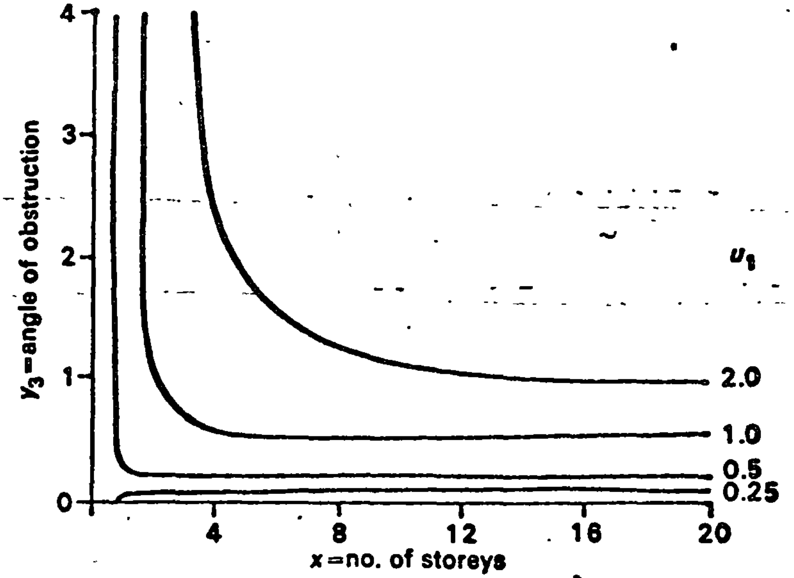

Fig. 3.18

the angle of obstruction is about 26° which is reasonable in residential developments:

$$\text{For } \psi_2(x),\ \frac{\mathrm{d}u_2}{\mathrm{d}x} = \psi_2'(x) = \frac{\lambda f h y_3}{(hx+fy_3+g-i)^2}, \text{ with varying } u_1, \tag{50}$$

$$= \frac{u_1}{x^2}, \text{ with varying } y_3,$$

and $\psi_2'(x)>0$ unequivocally in both cases, so that the open space index increases, as might be expected, with increasing number of storeys. In both cases the open space index approaches a limit

$$\lim_{x\to\infty} \psi_2(x) = 1. \tag{51}$$

This is a nice mathematical limit: it means that when the built forms 'are' infinitely high they occupy no land so that the whole site is open space.

$$\text{For } \psi_3(x), \frac{du_3}{dx} = \psi_3'(x) = \beta\lambda f y_3 \cdot \frac{\{(1-\lambda)fy_3+g-i\}}{\{hx+(1-\lambda)fy_3+g-i\}^2}$$

$$= \frac{-\beta u_1^2}{(\beta x-u_1)^2} \tag{52}$$

and when the angle of obstruction is held constant $\psi_3'(x) >, =,$ or <0 according to whether $(1-\lambda)fy_3+g-i >, =,$ or <0; that is, whether $y_3 >, =,$ or $<(i-g)/(1-\lambda)f$. The function tends to a limit,

$$\lim_{x\to\infty} \psi_3(x) = \frac{\beta\lambda f y_3}{h}. \tag{53}$$

This is the same as $\lim_{x\to\infty} \psi_1(x)$ because

$$\lim_{x\to\infty} \psi_3(x) = \lim_{x\to\infty} \psi_1(x)/\lim_{x\to\infty} \psi_2(x)$$

and as was seen from Equation 51 $\lim_{x\to\infty} \psi_2(x) = 1$.

Note that if $i = 0$, $\psi_3'(x) > 0$. That is to say, in the Heiligenthal–Gropius model the density of persons to open space always *increases* with the number of storeys when the angle of obstruction is held constant. This means that the amount of open space per person diminishes with building height. Beckett's model contradicts this statement, and yet this contradiction arises solely because of a refinement to measure the angle of obstruction above the ground level rather than at it! Beckett, as has been noted, ignored the parapet height, g, and with the values of the variables he used he obtained the condition $y_3 >, =,$ or <0.8. In most planned urban situations† the condition $y_3 < 0.8$ will hold – the angle of obstruction will be less than 38°40′. But if it is assumed with Gropius that the built form has a parapet, let us say $g = 0.3h$, then the condition becomes $y_3 >, =,$ or <0.4, and the critical angle of obstruction becomes 21°48′, an angle less than that which might be expected in most urban situations where a choice is to be made between low-rise or high-rise building. In this case, the open space per person definitely *decreases* with higher development. It may seem curious that policies about high or low building may hinge in the end on the detailed design of the roof fascia, but such is the case. Yet this exaggerates the real situation in practice. The point is that the increases or decreases are likely to be slight anyway, especially beyond four or so storeys. When the floorspace index is held constant then the amount of open space per person unequivocally increases with height: this is demonstrated by the second expression

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† This may not be true in tropical cities where larger angles of obstruction are acceptable

$$\psi_3'(x) = \frac{-\beta u_1^2}{(\beta x-u_1)^2} < 0.$$

(Remember that $\psi_3(x)$ is the density of population to open space, as this decreases so the amount of open space per person increases.)

$$\text{For} \qquad \phi_3(x), \frac{dy_3}{dx} = \phi_3'(x) = \frac{-u_1}{f} \cdot \frac{hu_1+\beta\lambda(g-i)}{(\beta\lambda x-u_1)^2}, \tag{54}$$

and $\phi_3'(x) >, =,$ or <0 if $hu_1+\beta\lambda(g-i) <, =,$ or >0; that is, if $u_1 <, =,$ or $>\beta\lambda(i-g)/h$. With $\beta = 1$, $\lambda = 0.75$, $i = 0.6h$, $g = 0.3h$ as before, this condition says that the angle of obstruction increases, is stationary, or decreases with height depending on whether the constant floorspace index is less than, equal to, or greater than 0.225. Thus except in low-density situations the lighting conditions can be expected to improve with increasing number of storeys. Setting $i = 0$ confirms the earlier Heiligenthal–Gropius theorem (6).

The Beckett theorems

THEOREM 7. *Assuming a constant angle of obstruction between parallel and equal built forms, the population density† increases hyperbolically, is stationary, or decreases hyperbolically with increasing number of storeys according to whether the angle of obstruction is greater than, equal to, or less than arc tan* $(i-g)/f$.‡

Corollary. *The order of the rate of change in the population density varies inversely with the square of the number of storeys, this density asymptotically approaching a limiting value for a very large number of storeys given by* $\lambda f y_3/h$.

THEOREM 8. *Assuming either a constant angle of obstruction between parallel and equal built forms, or a constant population density for such a development, the open space index increases hyperbolically with increasing number of storeys.*

Corollary. *The order of the rate of increase in the open space index varies inversely with the square of the number of storeys, the index asymptotically approaching an upper limit of 1 for a very large number of storeys.*

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† See definition above, p. 81. When $\beta = 1$, the population density [illegible] floorspace index, otherwise it is bed spaces, persons, rooms, etc., per unit a[illegible]ng to the precise definition of β.

‡ For this and following theorems the variables are as defined e[illegible] 1.

THEOREM 9. *Assuming a constant population density for a development of parallel and equal built forms, the density of persons to open space decreases with increasing number of storeys. (The amount of open space per person increases.)*

Corollary. *The order of the rate of increase of the density of persons to open space varies inversely with the square of the number of storeys, the density asymptotically approaching a lower limit equal to the population density.*

THEOREM 10. *Assuming a constant angle of obstruction between parallel and equal built forms the density of persons to open space increases hyperbolically, is stationary, or decreases hyperbolically with increasing number of storeys according to whether the angle of obstruction is greater than, equal to, or less than arc tan $(i-g)/(1-\lambda)f$.*

Corollary. *The order of the rate of change of the density of persons to open space varies inversely with the square of the number of storeys, this density asymptotically approaching a limiting value for a very large number of storeys equal to the limiting value of the population density, $\lambda f y_3/h$.*

THEOREM 11. *Assuming a constant population density for a development of parallel and equal built forms, the angle of obstruction increases hyperbolically, is stationary, or decreases hyperbolically according to whether the population density is less than, equal to, or greater than $\beta\lambda(i-g)/h$.*

Corollary. *The order of this change in the angle of obstruction varies inversely with the square of the number of storeys, approaching a limiting value for a very large number of storeys, arc tan $hu_1/\beta\lambda f$.*

The Heiligenthal–Gropius model showed that the relationships were not linear but hyperbolic, and in terms of the specification of that model the functions behaved consistently. The Beckett model demonstrates that a small refinement introduced into the model can significantly change the behaviour of the representative functions, and that detailed design factors, such as the height of the parapet, may be critical. As our models become more and more refined to take into account this and that factor the behaviour of these functions is likely to become more 'erratic', being dependent on a variety of *critical* relationships. The number of possible situations (defined by giving values to the independent variables) becomes very large and computing will usually have to be resorted to.†

But each refinement should be carefully considered. The reason Beckett chose a higher reference point for the angle of obstruction was in order better to estimate the level of daylight illumination in the ground floor rooms. Yet is this improvement in accuracy, if it be so, worth the considerable complications that it leads to? Recent work by Hawkes and Stibbs† on the effects of urban obstructions, such as motorways, on daylight suggests that the choice of reference point makes very little difference to the value of the external daylight factor (sky component and external reflected component) as measured on the vertical face of the ground storey. Thus, for practical purposes, the Heiligenthal–Gropius model is probably as good as Beckett's, and it is, of course, a good deal simpler to use and to understand. Nevertheless the Beckett model serves as an excellent illustration of the complex behaviour of a few variables describing a simple architectural system. There is no doubt that models can always be made more and more complicated, but the real challenge is to make them simple, stripped down until the quintessential structure of the problem is exposed.

Example four

Do other building forms use land differently from the layout of parallel blocks?

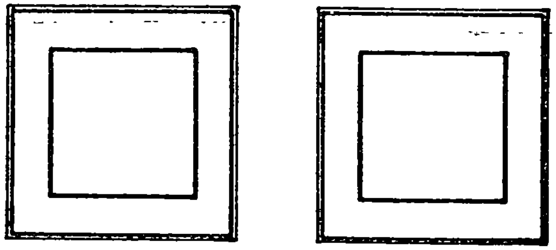

Fig. 3.19a. Ground coverage of 4-storey apartment buildings with interior courts.

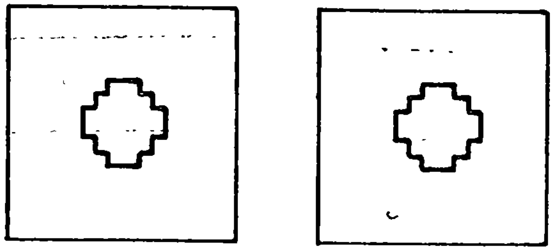

Fig. 3.19b. Ground coverage of 32-storey Sunlight Towers of same apartment capacity but with surrounding open areas.

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† See, for example, the environmental model described by Hawkes and Stibbs (1969) which can simulate highly complex architectural situations for the purposes of investigating lighting, heating and cooling, and acoustic performance.

† Private communication.

In 'Flach-, mittel- oder hochbau?' Walter Gropius demonstrates his main thesis by means of a diagram (Fig. 3.19) showing a 4-storey court development and a 32-storey tower scheme each of which contains the same number of apartments. This diagram can be taken as a starting point, simplifying the form of the 'Sunlight Tower' to a simple square plan. For the purposes of this demonstration the details of parapets and heights of reference points can be ignored, although, as has just been demonstrated, the models may be quite sensitive to these. Refinements, as always, can come later. Here the variables are defined as (Figs 3.20, 3.21):

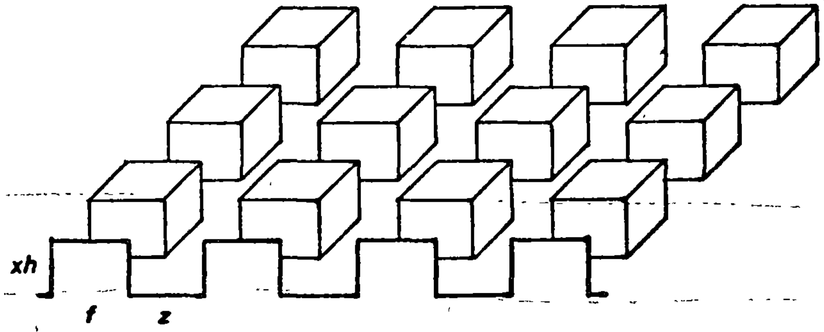

Fig. 3.20

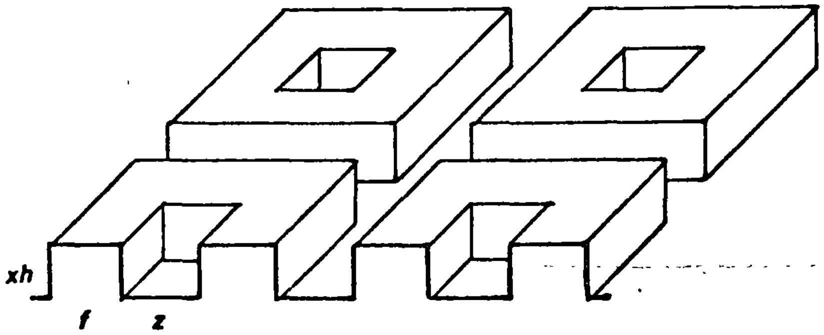

Fig. 3.21

f = width of built form,
h = height of a storey,
z = distance between blocks,
x = number of storeys,
y_1 = site area,
y_2 = total floor area,
y_3 = tangent of angle of obstruction.

The principal dependent variable is

$$u = y_2/y_1 = \text{the floorspace index.}$$

The other dependent variables for the two developments can be identified by the superscripts [0] and [2] for the tower and court respectively.† Thus $y_1^{[0]}$ represents the floor area of the tower; $y_2^{[2]}$ the site area of the court. In this exercise y_3 is treated as an independent variable. By the geometry of the arrangements, the following relations hold:

	Tower$^{[0]}$	Court$^{[2]}$	
For the site area	$y_1^{[0]} = (f+z)^2$,	$y_1^{[2]} = 4(f+z)^2$,	(55)
for the floor area	$y_2^{[0]} = f^2x$,	$y_2^{[2]} = 4f(f+z)x$,	(56)

$$\text{for the tangent of the obstruction angle } y_3 = \frac{hx}{z}. \tag{57}$$

From Equation 57, $z = hx/y_3$ so that, eliminating z from equations 55 and 56, the expressions for the floorspace indices, $u^{[0]}$ and $u^{[2]}$, are derived

$$u^{[0]} = \left(\frac{fy_3}{fy_3+hx}\right)^2 \cdot x \tag{58$^{[0]}$}$$

$$u^{[2]} = \left(\frac{fy_3}{fy_3+hx}\right) \cdot x. \tag{58$^{[2]}$}$$

The form of equation 58$^{[2]}$ is familiar. As in the previous example the function may be plotted as a hyperbola being a particular kind of quadratic expression in $u^{[2]}$ and x, in which the term of highest order is $u^{[2]}x$. This is not so in the case of equation 58$^{[0]}$. Here the term of highest order is $u^{[0]}x^2$ which is 'cubic'. The behaviour of this function for the tower block is distinctly different from that of our earlier examples. Let us take a close look at $u^{[0]} = \phi^{[0]}(x)$. Note that $\phi^{[0]}(0) = 0$ and that $\lim_{x\to\infty}\phi^{[0]}(x) = 0$. Also, differentiating,

$$\frac{du^{[0]}}{dx} = \phi^{[0]\prime}(x) = \frac{(fy_3)^2(fy_3-hx)}{(fy_3+hx)^3}, \tag{59$^{[0]}$}$$

so that $\phi^{[0]\prime}(x) >, =,$ or <0 according to whether $y_3 >, =,$ or $< hx/f$. For any given finite value of y_3 the function is stationary at $x = fy_3/h$ and this is in fact a maximum value. Thus, with a tower building an increase in the number of storeys at first increases the floorspace index, and then, passing a maximum value, decreases the index. The maximum value of the

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† This notation derives from March and Trace (1968).

floorspace index for any given value of y_3 is then given by substituting fy_3/h for x in equation $58^{[0]}$:

$$u^{[0]}_{\max} = \frac{fy_3}{4h}. \tag{$60^{[0]}$}$$

The behaviour of the court is, as has been said, more familiar. $\phi^{[2]}(0) = 0$, and $\lim_{x \to \infty} \phi^{[2]}(x) = fy_3/h$. Also, differentiating, it develops into

$$\frac{du^{[2]}}{dx} = \phi^{[2]\prime}(x) = \left(\frac{fy_3}{fy_3 + hx}\right)^2 > 0, \tag{$59^{[2]}$}$$

so that the function monotonically increases to a maximum value at infinity. That is to say, the court form tends to a limiting index of fy_3/h which is *four* times greater than the maximum achievable by the tower form. Perhaps a more realistic comparison is to see what the floorspace index of the court form is for the same number of storeys required to maximise the tower solution, namely $x = fy_3/h$.

$$u^{[2]} = \frac{fy_3}{2h} \tag{$60^{[2]}$}$$

which is just *twice* the value of $u^{[0]}_{\max}$. Thus when the tower form's index is at its maximum, a court of similar height will achieve two times as much floorspace.

This can be put yet another way round. What height does a court have to be to achieve the same floorspace index as the maximum achievable in tower development? This requires that

$$u^{[2]} = u^{[0]}_{\max}$$

or

$$\left(\frac{fy_3}{fy_3 + hx}\right) \cdot x = \frac{fy_3}{4h}, \tag{61}$$

whence we find

$$x = \frac{fy_3}{3h}.$$

Thus the number of storeys required is precisely *one-third* of those needed to maximise the index for the tower ($x_{\max} = fy_3/h$, see above).

How do these forms compare with the land use performance of parallel rows? Similar notation is used to define the variables shown in Fig. 3.22 for parallel blocks. The following equations are then derived (the superscript $^{(2)}$ is used for this form):

For the site area $$y_1^{(2)} = (f + z)^2, \tag{$55^{(2)}$}$$

for the floor area $$y_2^{(2)} = f(f + z) \cdot x, \tag{$56^{(2)}$}$$

and the tangent of the obstruction angle is as before (Equation 57). Thus eliminating z, the following is obtained:

For the floorspace index $$u^{(2)} = \left(\frac{fy_3}{fy_3 + hx}\right) \cdot x, \tag{$58^{(2)}$}$$

which is exactly the same as for the court form's index, $u^{[2]}$ (see Equation $58^{[2]}$). The freestanding court and the street form behave in identical ways.

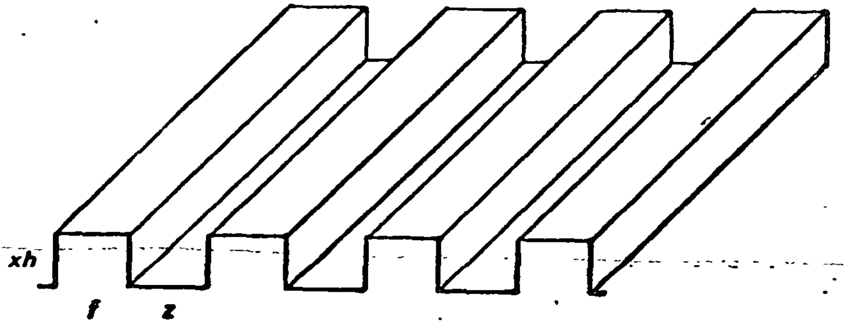

Fig. 3.22

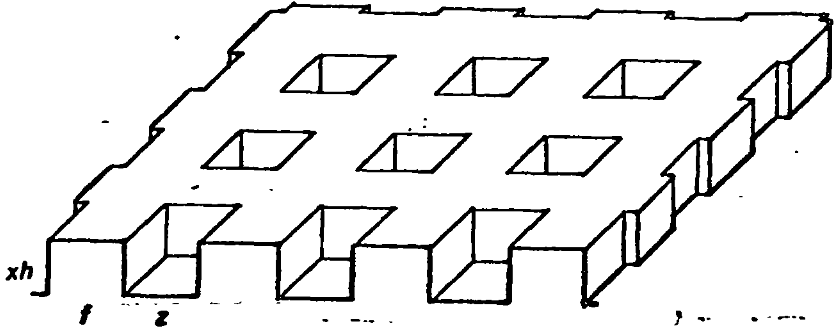

Fig. 3.23

The important point to recognise here is that any extrapolation from the performance of parallel blocks of the Heiligenthal-Gropius model to the behaviour of isolated towers with four incident faces is totally unwarranted. Yet such an extrapolation has been an essential part of the conventional wisdom on these matters.

Is there a form which can improve on the street and isolated court forms? Looking at the cruciform shown in Fig. 3.23, it is clear that many of these, by connecting, constitute a continuous series of courts. How does such a highly reticulated system behave in comparison with the more nucleated court and tower? Using a similar notation and defining the variables by Fig. 3.23 the following is obtained (a superscript $^{(4)}$ is employed for the cruciform):

$$\text{For the site area } y_1^{(4)} = (f+z)^2, \tag{55$^{(4)}$}$$

$$y_2^{(4)} = f(f+2z)\cdot x, \tag{56$^{(4)}$}$$

and once again $y_3 = hx/z$. Eliminating z, the result is

$$\text{for the floorspace index } u^{(4)} = \frac{fy_3(fy_3+2hx)}{(fy_3+hx)^2}\cdot x. \tag{58$^{(4)}$}$$

This is a third order expression in $u^{(4)}$ and x. But unlike equation $58^{[0]}$ the function $u^{(4)} = \phi^{(4)}(x)$ tends to a non-zero limit, in fact a maximum value given by $\lim_{x\to\infty} \phi^{(4)}(x) = 2fy_3/h$ which is *twice* the limiting index of the isolated court or the parallel block (for example, see equation $60^{[2]}$). When the tower reaches its maximum value, the cruciform obtains an index value

$$u^{(4)} = \frac{3}{4}\cdot\frac{fy_3}{h} \tag{60$^{(4)}$}$$

for the same number of storeys $x = fy_3/h$. This is a floorspace index *three* times as great as the maximum achievable in the tower form.

It is the tower (pavilion), parallel block (street) and continuous court forms that Martin and March compared in their article 'Land use and built forms' in 1966.† The example above makes somewhat different assumptions, but the same general pattern emerges. This pattern can best be seen by re-writing equations $58^{[0]}$, $58^{(2)}$ and $58^{(4)}$ in such a way that it is possible to generalise (braces are used to stand for either square or round brackets):

$$\text{The pavilion form} \quad u^{\{0\}} = fy_3\frac{(fy_3+0\cdot hx)}{(fy_3+hx)^2}\cdot x, \tag{61}$$

$$\text{the street form} \quad u^{\{2\}} = fy_3\frac{(fy_3+1\cdot hx)}{(fy_3+hx)^2}\cdot x,$$

$$\text{the court form} \quad u^{\{4\}} = fy_3\frac{(fy_3+2\cdot hx)}{(fy_3+hx)^2}\cdot x.$$

The general equation

$$u^{\{2\alpha\}} = fy_3\frac{(fy_3+\alpha\cdot hx)}{(fy_3+hx)^2}\cdot x, \quad \text{for } \alpha = 0,1,2 \tag{62}$$

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† See also parallel work by Eckhard Schulze-Fielitz (1968).

describes all the situations we have discussed above. From this it is easy to see that

$$u^{\{4\}} - u^{\{2\}} = u^{\{2\}} - u^{\{0\}} = \frac{fhy_3x^2}{(fy_3+hx)^2} \tag{63}$$

so that for all $x > 0$ the following may be written:

$$u^{\{4\}} > u^{\{2\}} > u^{\{0\}} \tag{64}$$

a statement which says that the land use performance of arrays of built forms in this Martin–March model are ranked unequivocally: for a given number of storeys the floorspace index for the continuous court form is greater than that for an array of streets (parallel blocks) which, in turn, is greater than that for an array of pavilions (towers). And, in particular, for the number of storeys giving the maximum value of the index for an array of pavilions, the floorspace index of a street array is *twice* that of the pavilion array and that of the continuous court array *three* times that of the pavilion array. Two simple theorems may now be stated relating to the Martin–March model:

THEOREM 12. *Comparing infinite arrays of rectangular built forms controlled by a given angle of obstruction, the floorspace index of an array of continuous courts is always greater than that of an array of streets, which, in turn, is always greater than that of an array of pavilions for any given number of storeys.*

THEOREM 13. *There is a maximum floorspace index for an array of pavilions for some finite number of storeys, and for this same number of storeys the indices for street and continuous court arrays are two and three times the maximum achievable by the pavilion array, respectively.*

Of course, this model is a gross oversimplification in practical terms, and many objections can be raised. More and more elaborate models can be designed in an attempt to overcome some of these criticisms. March and Trace (1968),† for example, investigate a finer range of elemental built forms which can be combined to produce more complex arrangements; they look at systematic transformations of these forms, and they discuss the relation of their work to previous studies in this field including the problem of sidelighting to tower forms (the argument that the open development of high-rise towers gains far more in daylighting terms from light coming around obstructing blocks than is lost by increased vertical obstruction). Such elaborations lead to a more tedious mathematical discussion which would be out of place here, but it is not necessarily a more advanced one.

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† For a more easily available digest of this work see Hutchinson (1970).

To bring more realism into such models is to lose generality (see Chapter 7). Nevertheless more sophisticated computer representations such as those by Hawkes and Stibbs (1969) allow a much more sensitive study of the environmental effects of buildings upon one another. Hawkes (1970) in a series of controlled experiments cautions against the indiscriminate use of generalisation in actual building design. As he points out there are many detailed points of design such as depth of window reveals, size and shape of openings, the specific physical properties of materials which affect significantly the environmental performance of groups of buildings. Nevertheless, simple models such as those described above do allow our more empirical experiments to be organised, do prompt important and serious questions, do act critically on our prejudices and the conventional wisdom, and do lead to speculations over far wider areas of study.

Elementary mathematical models are an excellent source of enquiry and are frequently suggestive of a systematic approach to computer-based experiment and investigation (Hawkes 1970, Tabor 1970). Finally, in practice they may help clear away some of the misleading 'rules-of-thumb' which frequently lurk behind design decisions, and they may help to replace these by more cautious generalisations, but, be warned – these may be equally misleading if results and conclusions are extrapolated beyond the simplifying assumptions of the original model.

4. *The use of models in planning and the architectural design process*[†]

NICHOLAS BULLOCK, PETER DICKENS & PHILIP STEADMAN

Three classes of model have been distinguished in American city planning research; descriptive models, predictive models, and planning models, in ascending order of difficulty. Ira Lowry has enumerated the features of the descriptive model in urban studies as follows: 'The builder of a descriptive model has the limited objective of persuading the computer to replicate the relevant features of an existing urban environment or of an already observed process of urban change. Roughly speaking, the measures of his accomplishment are: one, the ratio of input data required by the model to output data generated by the model; two, the accuracy and cost of the latter as compared to direct observation of the variables in question; and three, the applicability of his model to other times and places than that for which it was originally constructed.' (1965).

The descriptive model provides the planner with an insight into the workings of city structure but it does not directly allow him to predict future trends or to determine the effects of particular planning policies. This is done by means of the predictive model, for which it is necessary to specify mechanisms of cause and effect governing the variables whose values are simply observed in the descriptive model. In some cases the predictions may take a conditional form; that is to say the model is designed to operate so that 'if X occurs, then Y will follow', but takes no

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[†] This essay was written as an introduction to a report documenting work in progress in the Universities Study, in 1968. The main theme of the report was the necessity of finding some general framework whereby separate planning studies could be brought together and seen in a general relationship. The means for doing this was seen to be through the construction of mathematical models of university activity patterns, and the subsequent progress of this line of work is described in successive papers reproduced later in this volume. At the stage represented by this essay, however, it was felt necessary to try to make a general case for the use of models at all scales and in all areas of architectural and planning work, and for an experimental approach in environmental research as a whole. Hence the rather broad scope of the arguments, whose application goes beyond the narrower interests of university planning.

account of the actual likelihood of the occurrence of X. In this way the frame of reference of the model can be somewhat limited. It is nevertheless impossible to treat all external (exogenous) variables conditionally, since not all will operate independently of each other. We cannot assume both that 'if A occurs, then B will follow, and if X occurs then Y will follow' since the occurrence of A may preclude or affect the occurrence of X.

Planning models, the third type, form a class whose technology is not far developed. In planning models a measure of optimisation is introduced in terms of chosen criteria, in order to determine means of achieving stated planning goals. 'The essential steps are as follows: one, specification of alternative programs or actions that might be chosen by the planner; two, prediction of the consequences of choosing each alternative; three, scoring these consequences according to a metric of goal-achievement; and four, choosing the alternative which yields the highest score.' (Lowry, 1965). Since a wide choice of planning alternatives exists at each stage in the 'decision-tree' the number of overall possibilities rapidly becomes astronomic, but the use of computer programs to carry out steps three and four allows the examination of a fairly large number of alternative decision sequences.

The urban planning problems to which the American model-builders have applied their techniques have tended naturally to arise in the control and direction of powerful forces of change and growth in existing large cities. The future movements of a complex system are anticipated, and the effects of intervention from outside the system are measured – intervention in the form of public or private development programmes, or through planning controls and incentives of various kinds. What is important is that the model-building process takes up at a point in the history of the city's development when its 'design' or physical and organisational form is already well established. The model recognises the dynamic nature of a system in the process of change. The initial structure of the model is constituted by a current land use inventory by example, together with an analysis of the patterns of economic and social activity of the city's inhabitants at the present moment in time: trends are extrapolated forward as changes in this initial structure.

Such an approach has no application to the initial design of an accommodation for a new activity of whatever complexity on a virgin site. Not that the simulation of the performance of finished designs would not provide an invaluable means for their comprehensive evaluation and analysis. Nor can it be said that the study of urban models would not serve to illuminate the characteristic structure of the design problems of cities and acquaint the designer with the context for new solutions. It is in the creation of new forms that even models of the American planning type offer no direct help – for their role is in evaluation only, and alternative plans must be specified complete in advance of the model's operation. The truly inventive phase of the design process is that in which a form is synthesised in response to a programme. This will be discussed first in relation to the single building, since it is on the building scale that most of our work has so far concentrated, and the problems, though severe, are patently less so than those on the scale of the large development. The same principles will, however, apply in the larger problem, as in the smaller. Successful modelling of the single building is a necessary first step towards the goal of a complete model of an institution as a whole.

The debate on the process of derivation of architectural forms is an old one. This is not the place for a historical account of functionalism. But it is important for our purposes to distinguish two very different functionalist standpoints, the one determinist, the other we might call 'moral'.

Extreme apologists of rationalism in architecture have claimed that the form of a building proceeds directly and logically from the technique of its construction and the purpose to which it is put. They have suggested particularly of the engineering structure that its design follows an inevitable process, through a kind of 'constructional fatalism'. Representative of this determinist attitude in architecture was Auguste Choisy, who in his 'Histoire de l'Architecture' (1899) saw building form as a logical consequence of a *technique* and *methode*, signifying not simply the tools and methods of the building trade but 'aspects of society as a whole'. Thus 'buildings classify themselves as witnesses fixing the way of life and the moral condition of humanity, age by age.' The Gothic cathedrals were ideal for this form of treatment, since the lack of historical documentation of individual architects and particular technical inventions allowed Choisy to assume 'a kind of abstract necessity' as instrumental in their design. 'L'arc-boutant (the flying buttress)... ne fut point inventé, il s'imposa.'

This is something rather different from simply applauding the design of buildings which are contrived, either consciously or unconsciously, to exemplify the principles of their construction and to characterise the function they are to perform. That is a moral attitude, a kind of aesthetic puritanism which is as old as Aristotle. Classical functionalist theory seized on the analogy of the natural organism as a perfect paradigm of the relation of form to function. 'Living organisms and works of art are definite after their kinds, which Nature and Man respectively form by qualifying matter. The quantity of matter used in any case is determined by the form subserved; the size of a particular organ, or part, is determined by its form, which again is determined by the form of the whole organism or work.' Emphasis on fitness for purpose, inner consistency in relating the parts of the whole and forming the whole from the parts, and above all the organic analogy, are themes which recur throughout functionalist theory in its many phases and guises.

The development of nineteenth-century biology provoked a deeper examination of the parallels between natural and artistic organisms, especially in terms of structure and process as well as just outward appearance. 'In art as in nature an organism is an assemblage of interdependent parts of which the structure is determined by the function and of which the form is an expression of the structure' wrote the American critic Montgomery Schuyler (1894). Just as the palaeontologist could reconstruct the whole organism from a few bones, so with the architectural organism 'a person sufficiently skilled in the laws of organic structure can reconstruct, from the cross-section of the pier of a Gothic cathedral, the whole structural system of which it is the nucleus and prefigurement. The design of such a building...is an imitation not of the forms of nature but of the processes of nature.' (Schuyler 1894.) It was for the theory of biological evolution to show how the 'design' of living organisms occurs through an immensely protracted process of trial and error. Genetic mutations occur accidentally, at random. Some are unfavourable, some neutral, some favourable. In the struggle for existence, natural selection eliminates the unfavourable mutations; the favourable ones, on the contrary, are preserved, and the organisms possessing them will more likely reproduce themselves. Later nineteenth-century theorists of architectural rationalism like Schuyler held that the creation of new architectural forms was also a process of gradual evolution.

The distinction between approval of the manifestly functional qualities of a finished design and insistence on the inevitable logic of the process of design is important for the would-be user of theoretical model-building methods. It is only if he were able to accept the latter position that he could go on to conclude that architectural problems might be solved algorithmically, 'i.e. by the employment of a mathematical or logical construction that acts as a program or an instruction manual'. This is a problem discussed by Maldonado and Bonsieppi in an article entitled 'Science and Design' (1964). Once all the variables entering into the solution of a problem are summarised, is a mathematical formulation sufficient, they ask, to provide all detailed determinative data? They are inclined to conclude hat mathematical techniques of problem-structuring are of instrumental ather than panacea value. 'For it is wrong to attempt to simulate the elationship of the designer to the problems facing him in the form of a simply determined system, because, after all, the process here discussed – is in every creative and inventive human behaviour – can, if at all, only be simulated with models on the level of complex probabilistic systems.'

It is not difficult to find many reasons for the indeterminacy of the architectural design process It arises because even an explicit and apparently rigorous statement of the aims of the design is necessarily still vague on some points. Even performance standards of a technical, quantifiable nature can be variable within wide ranges and the results still quite acceptable. Minimum daylight levels can be fixed for the performance of visual tasks: or maximum levels to avoid discomfort from glare. Choice in the area between the two extremes is a matter of taste, or even indifference. Again one might imagine in theory that one particular configuration of rooms in a building would suit the pattern of intercommunication of the occupants best, and minimise their time spent walking: but in practice it will be immaterial to people within quite wide limits what distance they travel, so long as it is not too far and the journeys are not too frequent. In short, there is so much 'slack' in the system that even on the most clearly defined criteria a variety of solutions to each aspect of the design will be equally acceptable. As Alexander says 'for most requirements it is important to satisfy them at a level which suffices to prevent misfit between the form and the context, and to do this in the least arbitrary manner possible'. (1964, p. 99.)[†] For this reason Alexander proposes treating both specific requirements, and requirements of less definable but nevertheless crucially important character – 'comfort', 'security' or 'variety', in different contexts, for instance – as binary variables, that is to say taking one of two possible values only. Either the requirement is satisfied ('fit') or it is not ('misfit'). A continuous variable taking a range of values would be treated as a 'fit' for all values lying above the required standard, and for all values below as a 'misfit'.

A great part of the systematic and detailed study of design problems is devoted to the establishing of minimum or maximum standards and thereby the ranges within which variables operate. It is, in the nature of the problem, only the extremes which are susceptible to accurate determination. The fact that discussion may often dwell on minimum standards does not mean to imply that these are reckoned to be desirable or even, in the light of other considerations, acceptable. The same is true of the measurement of average conditions as found in present practice. The intention is simply to demonstrate the cost or savings involved in lavish or parsimonious allowances, or the implications of a raising or lowering of present standards.

As has been emphasised before, it is by no means necessary that in taking the optimum solution (indeed if one can be defined) to each subsidiary problem, a satisfactory result will be achieved in the total design. Advantage must be weighed in one area against consequent penalties in another: and this may be a matter of fine judgement. Where the benefits

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[†] Cf. his note 6 on Herbert Simon and the concept of 'satisficing'.

and the costs are purely economic or can be expressed as such, a means of comparison exists; as Ira Lowry says 'the most comprehensive metric available in our society, whether we like it or not, is money'. (Lowry 1965, p. 161.) But where he must weigh comfort or convenience against monetary costs, every man's scale of values will be different.

It is easy to see why by contrast it was precisely in the area of engineering structures that the idea of the inevitability of the process of design arose. For it is here that performance requirements are most fully and accurately stated in advance, and where the criteria by which the success of the design is judged are unequivocal. A mechanism works or it does not, a structure either stays up or falls down. But Le Corbusier, for example, while admiring the integrity and economy of means of engineering works, recognised that although the engineer was guided by 'natural law' and mathematical calculation, he nevertheless did exercise an intuitive skill in design. 'The engineer...has his own aesthetic, for he must, in making his calculations, qualify some of the terms of his equation; and it is here that taste intervenes. Now, in handling a mathematical problem, a man is regarding it from a purely abstract point of view, and in such a state, his taste must follow a sure and certain path.' (1927, p. 19.)

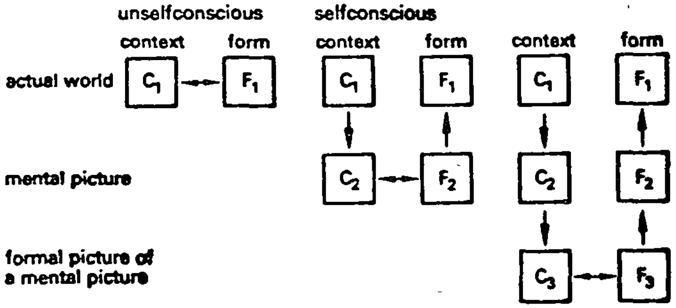

Fig. 4.1

Christopher Alexander attributes the very successful architecture of primitive cultures, as have critics before him, to the slow process by which its forms are evolved. He demands, however, a more explicit theory of adaptation than the 'vague hand-waving' of architectural Darwinism (1964, p. 37). Alexander draws a distinction between the 'unselfconscious' culture of primitive society, where the activity of 'design' is not recognised, where the user of a building is his own architect and the form evolves through the correction of individual technical failures as they occur; and the 'self-conscious' situation which obtains in our own culture, where design is the province of professionals, and is communicated through abstract principles and schemata. The 'unselfconscious' process relies on design being evolutionary rather than anticipatory, and on the existence of substantial forces of traditional taboo, as well as the slow movement of technical progress, to hold the evolving design steady. In the 'self-conscious' situation, instead of the form being shaped directly as a process of adaptation to the environment, this 'complex interaction between form and context' is modelled as a mental picture in the mind of the designer (Alexander 1964, ch. 6).† See Fig. 4.1.

Alexander argues that the unselfconscious process achieves success by virtue of the property of *homeostasis*, that is to say through being self-organising. The structure of the form-making system consists in a series of variables, or conditions which must be met to ensure 'good fit' between form and context; and the interaction between variables – causal linkages between one and another. See Fig. 4.2. (Alexander 1964, p. 43.)

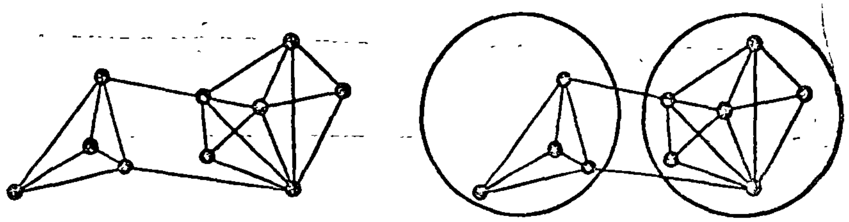

Fig. 4.2

'Since not all the variables are equally strongly connected (in other words there are not only dependences among the variables, but also independences), there will always be sub-systems...which can, in principle, operate fairly independently.' (Ibid.) These sub-systems, although interlinked, are yet 'sufficiently free of one another to adjust independently in a feasible amount of time'. The unselfconscious process works, 'because the cycles of correction and recorrection which occur during adaptation, are restricted to one sub-system at a time'. These kinds of dynamic systems

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† See also diagram p. 76 reproduced here as Fig. 4.1. The designer imagines such interaction: the interaction takes place between a conceptual picture of the context and a conceptual picture of the form (diagrams and pictures which stand for the form). The success of the method is plainly dependent on the ability of the designer to comprehend the total problem context, and to model the proposed form effectively in order that he may examine properly its inadequacies or advantages in relation to this context. As Alexander says 'in the unselfconscious process there is no possibility of misconstruing the situation: nobody makes a picture of the context, so the picture cannot be wrong'. But in the self-conscious process the context is only pictured, and the designer's difficulty is in making this picture as complete and accurate as possible.

acterise the biological world. Each system consists of many sub- loosely coupled; and the sub-systems themselves tend to consist maller systems, again more closely coupled internally yet less coupled between one another.

nselfconscious process any failure in the design, any 'misfit' will fect strongly only those variables encompassed in the particular em, and the failure will be resolved by an appropriate re-organisa- that sub-system. The self-conscious designer, in order to reduce to manageable proportions, attempts to pick out these sub-systems ch a nomenclature, and then manipulate areas of the design in independence of each other in a similar way.† The trouble as er sees it is that in practice the traditional categories, into which gn problem is intuitively analysed, tend not to correspond to its acture.

emedy for the failings of generalised concepts and categories, and bitrariness, is to reduce the listed variables making up a design mme to the level of specific detail. They 'must be chosen (1) to be al scope, (2) to be as independent of one another as is reasonably e, and (3) to be as small in scope and hence as specific and detailed erous as possible'. (Alexander 1964, p. 115.) The design process is ne of error reduction and the variables have to do with anticipated of stress or misfit between the context for a design and the 'domain s' which could conceivably be placed in this context.

omain 'may be thought of roughly as the set of all those dis- ble forms (good and bad) which might possibly be placed in contact he given context to complete the ensemble'. (Ibid., p. 103.) The es are to be equal in scope so that some requirements are not sub- partly or entirely within the broader frame of reference of others: following from this that they are independent of each other. Small pe also because in this way the prejudice of ready-made semantic ries – 'acoustics', 'economics' and so on – is avoided.

discussion so far concerns Alexander's account of the analytical only of the design programme. When it comes to the synthetic phase, realisation of the programme, Alexander seems to imply a degree of functional determinism, in introducing the notion of a 'unified description' of form and context. For some very simple objects, he says 'there is virtually no rift between formal and functional descriptions. Take a soap bubble for instance...

'The behaviour of soap films is so thoroughly understood that we know what shapes and sizes of bubbles different external conditions lead to. In this case, the formal descriptions and the functional descriptions are just different ways of saying the same things; we can say, if we like, that we have a unified description of a soap bubble.' (Ibid., p. 90.) Another example he takes is that of a road junction, where a diagrammatic representation of traffic flows as lines of different widths indicates directly the form the junction should take. The diagram is both a requirement diagram and a form diagram.

As he points out, however, there are few instances one can point to in the realm of man-made objects where the form has been uniquely determined by its requirements – the crane hook being thought to be one example (Archer 1956). The 'form diagram' can, in most design problems, be regarded as an exploratory tool, a tentative hypothesis about the matching of form to context, and like all hypotheses, derived through abstraction and invention. The process is that of the scientific method, where the hypothesis stands until shown to be false. It is measured against the requirements, by experiment, until a discrepancy between form and context is found. The hypothesis/diagram is then revised, and tested again.

It is important here, however, to emphasise the role in design of what might perhaps be called 'happy fit' as distinct from 'good fit': that is to say the possibility of finding a formal solution whose structure is particularly appropriate to the problem in hand but only through happy accident and not any kind of cause and effect. Such a possibility only arises through the relative 'slackness' of the programme requirements, whereby many alternative solutions are feasible. In this light, the soap-bubble example is misleading since no external purpose is recognised which the bubble fulfills; it exists as a natural phenomenon in its own right. It is a tension structure whose form is described completely by mathematical laws associated with the pressures exerted by the air. In the world of living organisms, similar tension structures are used for definite purposes to which they are admirably suited. But their forms cannot be ascribed simply to the moulding pressures arising from their functions: they are governed both by these *and* by independent structural laws of a general nature.

To take D'Arcy Thompson's classic example which approaches closest perhaps in the natural world to the problems of architecture: the honeycomb (Thompson 1942, pp. 499ff). The 'requirements' can be examined for an assembly of roughly cylindrical cells, stacked to fill space, strong and

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ander 1964, ch. 5. Alexander's analogy is that of a children's puzzle – one of shallow glass-topped boxes, where balls must be rolled into sockets. An im- nt child might well give the box a great shake and put it down, hoping for all the o fall in at once. His chances of success would be small, even if he repeated the hundreds of times. More sensibly he would tap gently, moving one ball at a ing care not to disturb those already in place. The designer must adopt tactics, solving each independent area of the design in turn, so that decisions a later stage do not invalidate the solutions to other 'sub-problems' already d.

economical of material. The process of the comb's construction can be observed: how cylinders, stacked, will tend to get moved into a hexagonal array and six sides be flattened out as the bees work, pressing against each other from opposite sides. But it can also be seen, at the same time, how the symmetrical forces of surface tension, working on the warm wax, will pull the comb's wall into the same configuration. The final form represents a resolution of structural forces as well as a consequence of the purpose for which it is made, but one does not necessarily follow from the other.

A vivid example of the same thing in architecture is in the uses made of the Buckminster Fuller hemispherical dome which is patently unsuitable as a house, despite Fuller's own personal example. It has a rigorous structural logic and virtually no flexibility of form: yet it has applications to which it is particularly appropriate, as for example in housing rotating radar scanners, or a use to which it is put in Cambridge – as an 'artificial sky' for architectural lighting experiments.

It is not only for 'engineering' structures that this fortuitous match between form and function is found. A similar match exists in the problems of the university teaching timetable: in how, given a structure of courses and thus a division of the student body into groups which must attend separate series of teaching 'events', these 'events' are then assigned to rooms so as to fulfil a number of limiting criteria, the most important of which will generally be economy in space (though not at the expense of some other educational considerations). Although these criteria can be stated with mathematical precision, timetabling problems do not allow of unique solutions. Instead a sensible strategy must be devised for searching through feasible alternatives, and a basis established for selecting better solutions. These better solutions will rely, in particular when a timetable is designed to suit an existing set of rooms, but also when a set of rooms is designed to suit a given structure of courses, on the particular combinations of class size and the fact that these happen to correspond, fortuitously, with room size.

Another example which is familiar to architects is the problem of planning a set of rooms of required sizes in a tight or limited configuration. Successful solutions may depend on purely fortuitous coincidence of dimensions or groups of dimensions – the rooms happen to fit together just so. There is no way of going about the problem that does not involve a certain amount of trial and error.

Although the characteristics of the architectural design process so far described can be summed up, it is necessary first to have an understanding of the detailed structure of the requirements, or context, of the problem, without the distortions arising out of ready-made semantic categories. Some of these requirements may be difficult to measure and therefore

indistinctly stated. The process of matching form to context is guided to a large degree by a correct interpretation of the structural nature of the problem; feasible alternative solutions are devised which are internally consistent and coherent in their own terms. These alternatives are then matched up to the context and their performance measured. Some solutions will be judged more successful than others, sometimes by virtue simply of a coincidental 'happy fit' of form and context. Where the scale of values by which performance is measured is essentially subjective and scientifically hard to define, or where performance on two disparate scales of value must be compared one against another, then opportunities must be presented to the designer or his client for the making of explicit judgement or choice in the matter.

The design process would therefore be considered to be largely a repetitive, cyclical one, in which the devising of preliminary solutions provokes a more explicit statement of the original requirements, and allows a progressively greater understanding of the structural nature of the problems in hand. Some of the choices and judgements which the designer or client must make only arise and only have meaning in relation to an intermediate solution, another reason why a measure of trial and error is inevitable. The fact that some requirements are mutually exclusive or work against each other in some way may similarly emerge only through the testing of alternative designs.

Now it is Alexander's contention that in architecture there is no means of generating ranges of alternative solutions symbolically (1964, p. 74), nor of expressing criteria for success in terms of a symbolic description of the form.

He instances certain kinds of problems which are capable of reduction to a matter of simple selection – 'like some of those that occur in economics, checkers, logic or administration, which can be clarified and solved mechanically'. It is impossible with architectural problems to generate a range of feasible, complete and finished solutions by a similar, single, uninterrupted, predetermined procedure of a mechanical nature. This, however, is no objection to a step-wise process, by which alternative preliminary forms or partial solutions are produced as a 'first hypothesis', evaluated, the terms of the problem somewhat revised, and a second series of appropriately modified forms tested again.

Now it is certainly true of a set of architectural drawings as a symbolic description that they present an inadequate means for a rigorous testing of the design against the programme requirements: building performance can only be assessed indirectly from them, by powerful exercise of the imagination or a great deal of prolonged and laborious calculation, depending on the characteristics of the design under consideration. As for the possibilities of full-scale experiment with real buildings, these are plainly limited since mistakes will be costly, and, in any case, identical circumstances are rarely repeated. But, as we have suggested before, the technique of simulating a design, either partial or complete, in the form of a computable model whose structure is mathematical, is exactly the way to evaluate its predicted performance with a high degree of realism. Calculations which were tedious and, in effect, impracticable for reasons of time become suddenly possible. Not only can external environmental conditions be simulated, but also the anticipated pattern of use of the building. Most important the pattern of use is not seen as something static and fixed, but as a dynamic process in time, over both the course of the day and the course of the years.

The unavoidably indeterminate way in which architectural problems are formulated, and the fact that as a consequence they may not be solved algorithmically, do not nevertheless imply that a strategy involving many successive alternate steps of design formulation and evaluation cannot be conducted in a perfectly logical, if not initially predetermined manner. The process allows the intervention of taste, judgement and invention at a series of intermediate stages; but with the cardinal advantage that these are exercised in relation to a clear statement of the structure of the problem and the issues at stake at each stage.

PART 2

ACTIVITIES, SPACE AND LOCATION

Introduction

From the more general work which has been indicated in the previous section, it seemed possible that studies might be developed at three different scales. The first is the scale of the individual building, at which level it might be possible to examine the internal and external relationships which affect the built form. The second is the scale of the urban sub-system, or, for example, the grouping of activities and buildings that are built up around the developing universities. The third scale is the major one of the urban system itself. All three of these programmes of work were in fact established by 1967. The first study to elaborate a method of work in Report form was the universities study, by Bullock, Dickens and Steadman, who produced their *Theoretical Basis for University Planning* in 1968.

The papers that follow were written at different points in that developing research programme. The first paper marked the end of the initial period of research. During this period, work on various parts of the programme was built up in some detail. An advance was made by the development of a method of studying timetabling and the relationship between numbers, intensity of use and space requirements of a given pattern of teaching (Toye 1968). Some of the earlier studies of the effect of different building forms on the use of land were given a more specific application, in which circulation and costs were taken into account. Some preliminary work was done on university residential accommodation and the effects of its location on the provision of other facilities on the campus itself.

But throughout all this work the main effort was to establish some means of examining the problem as a whole. What was required was the development of the kind of framework which would integrate hitherto isolated pieces of research and which, at the same time, would allow decisions made in one aspect of university planning, for instance numbers of students, to be seen in relation to the many other factors involved, for instance space. The proposal that a mathematical model should be used for this purpose

ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

(11)

11. SYNTHESIS OF THE FORM

Cristopher Alexander

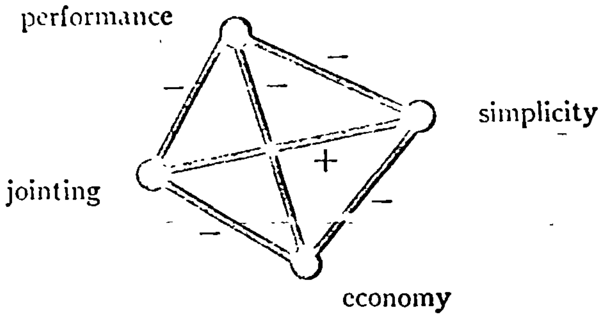
Harvard University Press, 1964.

1 / INTRODUCTION: THE NEED FOR RATIONALITY

These notes are about the process of design; the process of inventing physical things which display new physical order, organization, form, in response to function.

Today functional problems are becoming less simple all the time. But designers rarely confess their inability to solve them. Instead, when a designer does not understand a problem clearly enough to find the order it really calls for, he falls back on some arbitrarily chosen formal order. The problem, because of its complexity, remains unsolved.

Consider a simple example of a design problem, the choice of the materials to be used in the mass production of any simple household object like a vacuum cleaner. Time and motion studies show that the fewer different kinds of materials there are, the more efficient factory assembly is — and therefore demand a certain simplicity in the variety of materials used. This need for simplicity conflicts with the fact that the form will function better if we choose the best material for each separate purpose separately. But then, on the other hand, functional diversity of materials makes for expensive and complicated joints between components, which is liable to make maintenance less easy. Further still, all three issues, simplicity, performance, and jointing, are at odds with our desire to minimize the cost of the materials. For if we choose the cheapest material for each separate task, we shall not necessarily have simplicity, nor optimum performance, nor materials which can be cleanly jointed. Writing a minus sign beside a line for conflict, and a plus beside a line for positive agreement, we see that even this simple problem has the five-way conflict pictured below.



This is a typical design problem; it has requirements which have to be met; and there are interactions between the requirements, which makes the requirements hard to meet. This problem is simple to solve. It falls easily within the compass of a single man's intuition. But what about a more complicated problem?

Consider the task of designing a complete environment for a million people. The ecological balance of human and animal and plant life must be correctly adjusted both internally and to the given exterior physical conditions. People must be able to lead the individual lives they wish for. The social conditions induced must not lead to gross ill-health or to gross personal misery, and must not cause criminal delinquency. The cyclical intake of food and goods must not interfere with the regular movements of the inhabitants. The economic forces which develop must not lead to real-estate speculation which destroys the functional relation between residential areas and areas supporting heavy goods. The transportation system must not be organized so that it creates a demand that aggravates its own congestion. People must somehow be able to live in close cooperation and yet pursue the most enormous variety of interests. The physical layout must be compatible with foreseeable future regional developments. The conflict between population growth and diminishing water resources, energy resources, parklands, must somehow be taken care of. The environment must be organized so that its own regeneration and reconstruction does not constantly disrupt its performance.

As in the simpler example, each of these issues interacts with several of the others. But in this case each issue is itself a vast problem; and the pattern of interactions is vastly complicated. The difference between these two cases is really like the difference between the problem of adding two and two, and the problem of calculating the seventh root of a fifty digit number. In the first case we can quite easily do it in our heads. In the second case, the complexity of the problem will defeat us unless we find a simple way of writing it down, which lets us break it into smaller problems.

Today more and more design problems are reaching insoluble levels of complexity. This is true not only of moon bases, factories, and radio receivers, whose complexity is internal, but even of villages and teakettles. In spite of their superficial simplicity, even these problems have a background of needs and activities which is becoming too complex to grasp intuitively.

To match the growing complexity of problems, there is a growing body of information and specialist experience. This information is hard to handle; it is widespread, diffuse, unorganized.[1] Moreover, not only is the quantity of information itself by now beyond the reach of single designers, but the various specialists who retail it are narrow and unfamiliar with the form-makers' peculiar problems, so that it is never clear quite how the designer should best consult them.[2] As a result, although ideally a form should reflect all the known facts relevant to its design, in fact the average designer scans whatever information he happens on, consults a consultant now and then when faced by extra-special difficulties, and introduces this randomly selected information into forms otherwise dreamt up in the artist's studio of his mind. The technical difficulties of grasping all the information needed for the construction of such a form are out of hand — and well beyond the fingers of a single individual.[3]

At the same time that the problems increase in quantity, complexity, and difficulty, they also change faster than before. New materials are developed all the time, social patterns alter quickly, the culture itself is changing faster than it has ever changed before. In the past — even after the intellectual upheaval of the Renaissance — the individual designer would stand to *some* extent upon the shoulders of his predecessors. And although he was expected to make more and more of his own decisions as traditions gradually dissolved, there was always still some body of tradition which made his decisions easier. Now the last shreds of tradition are being torn from him. Since cultural pressures change so fast, any slow development of form becomes impossible. Bewildered, the form-maker stands alone. He has to make clearly conceived forms without the possibility of trial and error over time. He has

to be encouraged now to think his task through from the beginning, and to "create" the form he is concerned with, for what once took many generations of gradual development is now attempted by a single individual.[4] But the burden of a thousand years falls heavily on one man's shoulders, and this burden has not yet materially been lightened. The intuitive resolution of contemporary design problems simply lies beyond a single individual's integrative grasp.

Of course there are no definite limits to this grasp (especially in view of the rare cases where an exceptional talent breaks all bounds). But if we look at the lack of organization and lack of clarity of the forms around us, it is plain that their design has often taxed their designer's cognitive capacity well beyond the limit. The idea that the capacity of man's invention is limited is not so surprising, after all. In other areas it has been shown, and we admit readily enough, that there are bounds to man's cognitive and creative capacity. There are limits to the difficulty of a laboratory problem which he can solve;[5] to the number of issues he can consider simultaneously;[6] to the complexity of a decision he can handle wisely.[7] There are no absolute limits in any of these cases (or usually even any scale on which such limits could be specified); yet in practice it is clear that there are limits of some sort. Similarly, the very frequent failure of individual designers to produce well organized forms suggests strongly that there are limits to the individual designer's capacity.

We know that there are similar limits to an individual's capacity for mental arithmetic. To solve a sticky arithmetical problem, we need a way of setting out the problem which makes it perspicuous. Ordinary arithmetic convention gives us such a way. Two minutes with a pencil on the back of an envelope lets us solve problems which we could not do in our heads if we tried for a hundred years. But at present we have no corresponding way of simplifying design problems for ourselves. These notes describe a way of representing design problems which does make them easier to solve. It is a way of reducing the gap between the designer's small capacity and the great size of his task.

Part One contains a general account of the nature of design problems. It describes the way such problems have been solved in the past: first, in cultures where new problems are so rare that there are no actual designers; and then, by contrast, in cultures where new problems occur all the time, so that they have to be solved consciously by designers. From the contrast between the two, we shall learn how to represent a design problem so that it can be solved. Part Two describes the representation itself, and the kind of analysis the representation allows. Appendix 1 shows by example how the method works in practice.

The analysis of design problems is by no means obviously possible. There is a good deal of superstition among designers as to the deathly effect of analysis on their intuitions — with the unfortunate result that very few designers have tried to understand the process of design analytically. So that we get off to a fair start, let us try first to lay the ghosts which beset designers and make them believe that analysis is somehow at odds with the real problem of design.

It is not hard to see why the introduction of mathematics into design is likely to make designers nervous. Mathematics, in the popular view, deals with magnitude. Designers recognize, correctly, that calculations of magnitude only have

strictly limited usefulness in the invention of form, and are therefore naturally rather skeptical about the possibility of basing design on mathematical methods.[8] What they do not realize, however, is that modern mathematics deals at least as much with questions of order and relation as with questions of magnitude. And though even this kind of mathematics may be a poor tool if used to prescribe the physical nature of forms, it can become a very powerful tool indeed if it is used to explore the conceptual order and pattern which a problem presents to its designer.

Logic, like mathematics, is regarded by many designers with suspicion. Much of it is based on various superstitions about the kind of force logic has in telling us what to do. First of all, the word "logic" has some currency among designers as a reference to a particularly unpleasing and functionally unprofitable kind of formalism.[9] The so-called logic of Jacques François Blondel or Vignola, for instance, referred to rules according to which the elements of architectural style could be combined.[10] As rules they may be logical. But this gives them no special force unless there is also a legitimate relation between the system of logic and the needs and forces we accept in the real world. Again, the cold visual "logic" of the steel-skeleton office building seems horribly constrained, and if we take it seriously as an intimation of what logic is likely to do, it is certain to frighten us away from analytical methods.[11] But no one shape can any more be a consequence of the use of logic than any other, and it is nonsense to blame rigid physical form on the rigidity of logic. It is not possible to set up premises, trace through a series of deductions, and arrive at a form which is logically determined by the premises, unless the premises already have the seeds of a particular plastic emphasis built into them. There is no legitimate sense in which deductive logic can prescribe physical form for us.

But, in speaking of logic, we do not need to be concerned with processes of inference at all. While it is true that a great deal of what is generally understood to be logic is concerned with deduction, logic, in the widest sense, refers to something far more general. It is concerned with the form of abstract structures, and is involved the moment we make pictures of reality and then seek to manipulate these pictures so that we may look further into the reality itself. It is the business of logic to invent purely artificial structures of elements and relations. Sometimes one of these structures is close enough to a real situation to be allowed to represent it. And then, because the logic is so tightly drawn, we gain insight into the reality which was previously withheld from us.[12]

The use of logical structures to represent design problems has an important consequence. It brings with it the loss of innocence. A logical picture is easier to criticize than a vague picture since the assumptions it is based on are brought out into the open. Its increased precision gives us the chance to sharpen our conception of what the design process involves. But once what we do intuitively can be described and compared with nonintuitive ways of doing the same things, we cannot go on accepting the intuitive method innocently. Whether we decide to stand for or against pure intuition as a method, we must do so for reasons which can be discussed.

I wish to state my belief in this loss of innocence very clearly, because there are many designers who are apparently not willing to accept the loss. They insist that design must be a purely intuitive process: that it is hopeless to try and understand it sensibly because its problems are too deep.

There has already been one loss of innocence in the recent history of design; the discovery of machine tools to replace hand craftsmen. A century ago William Morris, the first man to see that the machines were being misused, also retreated from the loss of innocence. Instead of accepting the machine and trying to understand its implications for design, he went back to making exquisite handmade goods.[13] It was not until Gropius started his Bauhaus that designers came to terms with the machine and the loss of innocence which it entailed.[14]

Now we are at a second watershed. This time the loss of innocence is intellectual rather than mechanical. But again there are people who are trying to pretend that it has not taken place. Enormous resistance to the idea of systematic processes of design is coming from people who recognize correctly the importance of intuition, but then make a fetish of it which excludes the possibility of asking reasonable questions.

It is perhaps worth remembering that the loss of intellectual innocence was put off once before. In the eighteenth century already, certain men, Carlo Lodoli and Francesco Algarotti in Italy and the Abbé Laugier in France, no longer content to accept the formalism of the academies, began to have serious doubts about what they were doing, and raised questions of just the sort that have led, a hundred and fifty years later, to the modern revolutionary ideas on form.[15] Oddly enough, however, though these serious doubts were clearly expressed and widely read, architecture did not develop from them in the direction indicated. The doubts and questions were forgotten. Instead, in late eighteenth century Europe, we find evidence of quite another atmosphere developing, in which architects based their formal invention on the rules provided by a variety of manners and "styles" like neo-Tudor, neoclassicism, chinoiserie, and neo-Gothic.[16]

It is possible to see in this course of events a desperate attempt to ward off the insecurity of selfconsciousness, and to maintain the security of innocence.

Lodoli and Laugier wanted to know what they were doing as makers of form. But the search for this knowledge only made the difficulty of their questions clear. Rather than face the responsibility of these difficult questions, designers turned instead to the authority of resurrected "styles." The architectural decisions made within a style are safe from the nagging difficulty of doubt, for the same reason that decisions are easier to make under tradition and taboo than on one's own responsibility. It is no coincidence, in my opinion, that while the Renaissance had allowed free recombinations of classical elements, the neoclassicism which replaced it stuck as closely as it could to the precise detail of Greece and Rome. By leaning on correctness, it was possible to alleviate the burden of decision. To make the secession from responsibility effective, the copy had to be exact.[17]

Now it looks as though a second secession from responsibility is taking place. It is not possible today to escape the responsibility of considered action by working within academic styles. But the designer who is unequal to his task, and unwilling to face the difficulty, preserves his innocence in other ways. The modern designer relies more and more on his position as an "artist," on catchwords, personal idiom, and intuition -- for all these relieve him of some of the burden of decision, and make his cognitive problems manageable. Driven on his own resources, unable to cope with the complicated information he is supposed to organize, he hides his incompetence in a frenzy of artistic individuality. As his capacity to invent clearly conceived, well-fitting forms is exhausted further, the emphasis on intuition and individuality only grows wilder.[18]

In this atmosphere the designer's greatest gift, his intuitive ability to organize physical form, is being reduced to nothing by the size of the tasks in front of him, and mocked by the efforts of the "artists." What is worse, in an era that badly needs designers with a synthetic grasp of the organization of the physical world, the real work has to be done by less gifted engineers, because the designers hide their gift in irresponsible pretension to genius.

We must face the fact that we are on the brink of times when man may be able to magnify his intellectual and inventive capability, just as in the nineteenth century he used machines to magnify his physical capacity.[19] Again, as then, our innocence is lost. And again, of course, the innocence, once lost, cannot be regained. The loss demands attention, not denial.

PART ONE

2 / GOODNESS OF FIT

The ultimate object of design is form.

The reason that iron filings placed in a magnetic field exhibit a pattern — or have form, as we say — is that the field they are in is not homogeneous. If the world were totally regular and homogeneous, there would be no forces, and no forms. Everything would be amorphous. But an irregular world tries to compensate for its own irregularities by fitting itself to them, and thereby takes on form.[1] D'Arcy Thompson has even called form the "diagram of forces" for the irregularities.[2] More usually we speak of these irregularities as the functional origins of the form.

The following argument is based on the assumption that physical clarity cannot be achieved in a form until there is first some programmatic clarity in the designer's mind and actions; and that for this to be possible, in turn, the designer must first trace his design problem to its earliest functional origins and be able to find some sort of pattern in them.[3] I shall try to outline a general way of stating design problems which draws attention to these functional origins, and makes their pattern reasonably easy to see.

It is based on the idea that every design problem begins with an effort to achieve fitness between two entities: the form in question and its context.[4] The form is the solution to the problem; the context defines the problem. In other words, when we speak of design, the real object of discussion is not the form alone, but the ensemble comprising the form and its context. Good fit is a desired property of this ensemble which relates to some particular division of the ensemble into form and context.[5]

There is a wide variety of ensembles which we can talk about like this. The biological ensemble made up of a natural organism and its physical environment is the most familiar: in this case we are used to describing the fit between the two as well-adaptedness.[6] But the same kind of objective aptness is to be found in many other situations. The ensemble consisting of a suit and tie is a familiar case in point; one tie goes well with a certain suit, another goes less well.[7] Again, the ensemble may be a game of chess, where at a certain stage of the game some moves are more appropriate than others because they fit the context of the previous moves more aptly.[8] The ensemble may be a musical composition — musical phrases have to fit their contexts too: think of the perfect rightness when Mozart puts just *this* phrase at a certain point in a sonata.[9] If the ensemble is a truckdriver plus a traffic sign, the graphic design of the sign must fit the demands made on it by the driver's eye. An object like a kettle has to fit the context of its use, and the technical context of its production cycle.[10] In the pursuit of urbanism, the ensemble which confronts us is the city and its habits. Here the human background which defines the need for new buildings, and the physical environment provided by the available sites, make a context for the form of the city's growth. In an extreme case of this kind, we may even speak of a culture itself as an ensemble in which the various fashions and artifacts which develop are slowly fitted to the rest.[11]

The rightness of the form depends, in each one of these cases, on the degree to which it fits the rest of the ensemble.[12]

We must also recognize that no one division of the ensemble into form and context is unique. Fitness across any one such division is just one instance of the ensemble's internal coherence. Many other divisions of the ensemble will be equally significant. Indeed, in the great majority of actual cases, it is necessary for the designer to consider several different divisions of an ensemble, superimposed, at the same time.

Let us consider an ensemble consisting of the kettle plus everything about the world outside the kettle which is relevant to the use and manufacture of household utensils. Here again there seems to be a clear boundary between the teakettle and the rest of the ensemble, if we want one, because the kettle itself is a clearly defined kind of object. But I can easily make changes in the boundary. If I say that the kettle is the wrong way to heat domestic drinking water anyway, I can quickly be involved in the redesign of the entire house, and thereby push the context back to those things outside the house which influence the house's form. Alternatively I may claim that it is not the kettle which needs to be redesigned, but the method of heating kettles. In this case the kettle becomes part of the context, while the stove perhaps is form.

There are two sides to this tendency designers have to change the definition of the problem. On the one hand, the impractical idealism of designers who want to redesign entire cities and whole processes of manufacture when they are asked to design simple objects is often only an attempt to loosen difficult constraints by stretching the form-context boundary.

On the other hand, this way in which the good designer keeps an eye on the possible changes at every point of the ensemble is part of his job. He is bound, if he knows what he is doing, to be sensitive to the fit at several boundaries within the ensemble at once. Indeed, this ability to deal with several layers of form-context boundaries in concert is an important part of what we often refer to as the designer's sense of organization. The internal coherence of an ensemble depends on a whole net of such adaptations. In a perfectly coherent ensemble we should expect the two halves of every possible division of the ensemble to fit one another.

It is true, then, that since we are ultimately interested in the ensemble as a whole, there is no good reason to divide it up just once. We ought always really to design with a number of nested, overlapped form-context boundaries in mind. Indeed, the form itself relies on its own inner organization and on the internal fitness between the pieces it is made of to control its fit as a whole to the context outside.

However, since we cannot hope to understand this highly interlaced and complex phenomenon until we understand how to achieve fit at a single arbitrarily chosen boundary, we must agree for the present to deal only with the simplest problem. Let us decide that, for the duration of any one discussion, we shall maintain the same single division of a given ensemble into form and context, even though we acknowledge that the division is probably chosen arbitrarily. And let us remember, as a corollary, that for the present we shall be giving no deep thought to the internal organization of the form as such, but only to the simplest premise and aspect of that organization: namely, that fitness which is the residue of adaptation across the single form-context boundary we choose to examine.[13]

The form is a part of the world over which we have control, and which we decide to shape while leaving the rest of the

world as it is. The context is that part of the world which puts demands on this form; anything in the world that makes demands of the form is context. Fitness is a relation of mutual acceptability between these two. In a problem of design we want to satisfy the mutual demands which the two make on one another. We want to put the context and the form into effortless contact or frictionless coexistence.

We now come to the task of characterizing the fit between form and context. Let us consider a simple specific case.

It is common practice in engineering, if we wish to make a metal face perfectly smooth and level, to fit it against the surface of a standard steel block, which is level within finer limits than those we are aiming at, by inking the surface of this standard block and rubbing our metal face against the inked surface. If our metal face is not quite level, ink marks appear on it at those points which are higher than the rest. We grind away these high spots, and try to fit it against the block again. The face is level when it fits the block perfectly, so that there are no high spots which stand out any more.

This ensemble of two metal faces is so simple that we shall not be distracted by the possibility of multiple form-context boundaries within it. There is only one such boundary worth discussion at a macroscopic level, that between the standard face (the context), and the face which we are trying to smooth (the form.) Moreover, since the context is fixed, and only the form variable, the task of smoothing a metal face serves well as a paradigm design problem. In this case we may distinguish good fit from bad experimentally, by inking the standard block, putting the metal face against it, and checking the marking that gets transferred. If we wish to judge the form without actually putting it in contact with its context, in this case we may also do so. If we define levelness in mathematical terms, as a limitation on the variance which is permitted over the surface, we can test the form itself, without testing it against the context. We can do this because the criterion for levelness is, simultaneously, a description of the required form, and also a description of the context.

Consider a second, slightly more complex example. Suppose we are to invent an arrangement of iron filings which is stable when placed in a certain position in a given magnetic field. Clearly we may treat this as a design problem. The iron filings constitute a form, the magnetic field a context. Again we may easily judge the fit of a form by placing it in the magnetic field, and watching to see whether any of the filings move under its influence. If they do not, the form fits well. And again, if we wish to judge the fit of the form without recourse to this experiment, we may describe the lines of force of the magnetic field in mathematical terms, and calculate the fit or lack of fit. As before, the opportunity to evaluate the form when it is away from its context depends on the fact that we can give a precise mathematical description of the context (in this case the equations of the magnetic field).

In general, unfortunately, we cannot give an adequate description of the context we are dealing with. The fields of the contexts we encounter in the real world cannot be described in the unitary fashion we have found for levelness and magnetic fields. There is as yet no theory of ensembles capable of expressing a unitary description of the varied phenomena we encounter in the urban context of a dwelling, for example, or in a sonata, or a production cycle.

Yet we certainly need a way of evaluating the fit of a form which does not rely on the experiment of actually trying the form out in the real world context. Trial-and-error design is an admirable method. But it is just real world trial and error which we are trying to replace by a symbolic method, because real trial and error is too expensive and too slow.

The experiment of putting a prototype form in the context itself is the real criterion of fit. A complete unitary description of the demands made by the context is the only fully adequate nonexperimental criterion. The first is too expensive, the second is impossible: so what shall we do?

Let us observe, first of all, that we should not really expect to be able to give a unitary description of the context for complex cases: if we could do so, there would be no problems of design. The context and the form are complementary. This is what lies behind D'Arcy Thompson's remark that the form is a diagram of forces.[14] Once we have the diagram of forces in the literal sense (that is, the field description of the context), this will in essence also describe the form as a complementary diagram of forces. Once we have described the levelness of the metal block, or the lines of force of the magnetic field, there is no conceptual difficulty, only a technical one, in getting the form to fit them, because the unitary description of the context is in both cases also a description of the required form.

In such cases there is no design problem. *What does make design a problem in real world cases is that we are trying to make a diagram for forces whose field we do not understand.*[15] Understanding the field of the context and inventing a form to fit it are really two aspects of the same process. It is because the context is obscure that we cannot give a direct, fully coherent criterion for the fit we are trying to achieve; and it is also its obscurity which makes the task of shaping a well-fitting form at all problematic. What do we do about this difficulty in everyday cases? Good fit means something, after all — even in cases where we cannot give a completely satisfactory fieldlike criterion for it. How is it, cognitively, that we experience the sensation of fit?

If we go back to the procedure of leveling metal faces against a standard block, and think about the way in which good fit and bad fit present themselves to us, we find a rather curious feature. Oddly enough, the procedure suggests no direct practical way of identifying good fit. We recognize bad fit whenever we see a high spot marked by ink. But in practice we see good fit only from a negative point of view, as the limiting case where there are no high spots.

Our own lives, where the distinction between good and bad fit is a normal part of everyday social behavior, show the same feature. If a man wears eighteenth-century dress today, or wears his hair down to his shoulders, or builds Gothic mansions, we very likely call his behavior odd: it does not fit our time. These are abnormalities. Yet it is such departures from the norm which stand out in our minds, rather than the norm itself. Their wrongness is somehow more immediate than the rightness of less peculiar behavior, and therefore more compelling. Thus even in everyday life the concept of good fit, though positive in meaning, seems very largely to feed on negative instances; it is the aspects of our lives which are obsolete, incongruous, or out of tune that catch our attention.

The same happens in house design. We should find it almost

impossible to characterize a house which fits its context. Yet it is the easiest thing in the world to name the specific kinds of misfit which prevent good fit. A kitchen which is hard to clean, no place to park my car, the child playing where it can be run down by someone else's car, rainwater coming in, overcrowding and lack of privacy, the eye-level grill which spits hot fat right into my eye, the gold plastic doorknob which deceives my expectations, and the front door I cannot find, are all misfits between the house and the lives and habits it is meant to fit. These misfits are the forces which must shape it, and there is no mistaking them. Because they are expressed in negative form they are specific, and tangible enough to talk about.

The same thing happens in perception. Suppose we are given a button to match, from among a box of assorted buttons. How do we proceed? We examine the buttons in the box, one at a time; but we do not look directly for a button which fits the first. What we do, actually, is to scan the buttons, rejecting each one in which we notice some discrepancy (this one is larger, this one darker, this one has too many holes, and so on), until we come to one where we can see no differences. Then we say that we have found a matching one. Notice that here again it is much easier to explain the misfit of a wrong button than to justify the congruity of one which fits.

When we speak of bad fit we refer to a single identifiable property of an ensemble, which is immediate in experience, and describable. Wherever an instance of misfit occurs in an ensemble, we are able to point specifically at what fails and to describe it. It seems as though in practice the concept of good fit, describing only the absence of such failures and hence leaving us nothing concrete to refer to in explanation, can only be explained indirectly; it is, in practice, as it were, the disjunction of all possible misfits.[16]

With this in mind, I should like to recommend that we should always expect to see the process of achieving good fit between two entities as a negative process of neutralizing the incongruities, or irritants, or forces, which cause misfit.[17]

It will be objected that to call good fit the absence of certain negative qualities is no more illuminating than to say that it is the presence of certain positive qualities.[18] However, though the two are equivalent from a logical point of view, from a phenomenological and practical point of view they are very different.[19] In practice, it will never be as natural to speak of good fit as the simultaneous satisfaction of a number of requirements, as it will be to call it the simultaneous nonoccurrence of the same number of corresponding misfits.

Let us suppose that we did try to write down a list of all possible relations between a form and its context which were required by good fit. (Such a list would in fact be just the list of requirements which designers often do try to write down.) In theory, we could then use each requirement on the list as an independent criterion, and accept a form as well fitting only if it satisfied all these criteria simultaneously.

However, thought of in this way, such a list of requirements is potentially endless, and still really needs a "field" description to tie it together. Think, for instance, of trying to specify all the properties a button had to have in order to match another. Apart from the kinds of thing we have already mentioned, size, color, number of holes, and so on,

we should also have to specify its specific gravity, its electrostatic charge, its viscosity, its rigidity, the fact that it should be round, that it should not be made of paper, etc., etc. In other words, we should not only have to specify the qualities which distinguish it from all other buttons, but we should also have to specify all the characteristics which actually made it a button at all.

Unfortunately, the list of distinguishable characteristics we can write down for the button is infinite. It remains infinite for all practical purposes until we discover a *field description* of the button. Without the field description of the button, there is no way of reducing the list of required attributes to finite terms. We are therefore forced to economize when we try to specify the nature of a matching button, because we can only grasp a finite list (and rather a short one at that). Naturally, we choose to specify those characteristics which are *most* likely to cause trouble in the business of matching, and which are therefore most useful in our effort to distinguish among the objects we are likely to come across in our search for buttons. But to do this, we must rely on the fact that a great many objects will not even come up for consideration. There are, after all, conceivable objects which are buttons in every respect except that they carry an electric charge of one thousand coulombs, say. Yet in practice it would be utterly superfluous, as well as rather unwieldy, to specify the electrostatic charge a well-matched button needed to have. No button we are likely to find carries such a charge, so we ignore the possibility. The only reason we are able to match one thing with another at all is that we rely on a good deal of unexpressed information contained in the statement of the task, and take a great deal for granted.[20]

In the case of a design problem which is truly problematical, we encounter the same situation. We do not have a field description of the context, and therefore have no intrinsic way of reducing the potentially infinite set of requirements to finite terms. Yet for practical reasons we do need some way of picking a finite set from the infinite set of possible ones. In the case of requirements, no sensible way of picking this finite set presents itself. From a purely descriptive standpoint we have no way of knowing which of the infinitely many relations between form and context to include, and which ones to leave out.

But if we think of the requirements from a negative point of view, as potential misfits, there is a simple way of picking a finite set. This is because it is through misfit that the problem originally brings itself to our attention. We take just those relations between form and context which obtrude most strongly, which demand attention most clearly, which seem most likely to go wrong. We cannot do better than this.[21] If there were some intrinsic way of reducing the list of requirements to a few, this would mean in essence that we were in possession of a field description of the context: if this were so, the problem of creating fit would become trivial, and no longer a problem of design. We cannot have a unitary or field description of a context and still have a design problem worth attention.

In the case of a real design problem, even our conviction that there is such a thing as fit to be achieved is curiously flimsy and insubstantial. We are searching for some kind of harmony between two intangibles: a form which we have not yet designed, and a context which we cannot properly describe. The only reason we have for thinking that there must be some kind of fit to be achieved between them is that we can detect incongruities, or negative instances of it. The incongruities in an ensemble are the primary data of experience. If we agree to treat fit as the absence of misfits, and to use a list of those potential misfits which are most likely to occur as our criterion for fit, our theory will at least have the same nature as our intuitive conviction that there is a problem to be solved.

The results of this chapter, expressed in formal terms, are these. If we divide an ensemble into form and context, the fit between them may be regarded as an orderly condition of the ensemble, subject to disturbance in various ways, each one a potential misfit. Examples are the misfits between a house and its users, mentioned on page 23. We may summarize the state of each potential misfit by means of a binary variable. If the misfit occurs, we say the variable takes the value 1. If the misfit does not occur, we say the variable takes the value 0. Each binary variable stands for one possible kind of misfit between form and context.[22] The value this variable takes, 0 or 1, describes a state of affairs that is not either in the form alone or in the context alone, but a relation between the two. The state of this relation, fit or misfit, describes one aspect of the whole ensemble. It is a condition of harmony and good fit in the ensemble that none of the possible misfits should actually occur. We represent this fact by demanding that all the variables take the value 0.

The task of design is not to create form which meets certain conditions, but to create such an order in the ensemble that all the variables take the value 0. The form is simply that part of the ensemble over which we have control. It is only through the form that we can create order in the ensemble.

3 / THE SOURCE OF GOOD FIT

We must now try to find out how we should go about getting good fit. Where do we find it? What is the characteristic of processes which create fit successfully?

It has often been claimed in architectural circles that the houses of simpler civilizations than our own are in some sense better than our own houses.[1] While these claims have perhaps been exaggerated, the observation is still sometimes correct. I shall try to show that the facts behind it, if correctly interpreted, are of great practical consequence for an intelligently conceived process of design.

Let us consider a few famous modern houses for a moment, from the point of view of their good fit. Mies Van der Rohe's Farnsworth house, though marvelously clear, and organized under the impulse of certain tight formal rules, is certainly not a triumph economically or from the point of view of the Illinois floods.[2] Buckminster Fuller's geodesic domes have solved the weight problem of spanning space, but you can hardly put doors in them. Again, his dymaxion house, though efficient as a rapid-distribution mass-produced package, takes no account whatever of the incongruity of single free-standing houses set in the acoustic turmoil and service complexity of a modern city.[3] Even Le Corbusier in the Villa Savoie, for example, or in the Marseilles apartments, achieves his clarity

of form at the expense of certain elementary comforts and conveniences.[4]

Laymen like to charge sometimes that these designers have sacrificed function for the sake of clarity, because they are out of touch with the practical details of the housewife's world, and preoccupied with their own interests. This is a misleading charge. What is true is that designers do often develop one part of a functional program at the expense of another. But they do it because the only way they seem able to organize form clearly is to design under the driving force of some comparatively simple concept.

On the other hand, if designers do not aim principally at clear organization, but do try to consider all the requirements equally, we find a kind of anomaly at the other extreme. Take the average developer-built house; it is built with an eye for the market, and in a sense, therefore, fits its context well, even if superficially. But in this case the various demands made on the form are met piecemeal, without any sense of the overall organization the form needs in order to contribute as a whole to the working order of the ensemble.

Since everything in the human environment can nowadays be modified by suitable purchases at the five and ten, very little actually has to be taken care of in the house's basic organization. Instead of orienting the house carefully for sun and wind, the builder conceives its organization without concern for orientation, and light, heat, and ventilation are taken care of by fans, lamps, and other kinds of peripheral devices. Bedrooms are not separated from living rooms in plan, but are placed next to one another and the walls between them then stuffed with acoustic insulation.

The complaint that macroscopic clarity is missing in these cases is no aesthetic whim. While it is true that an individual problem can often be solved adequately without regard for the fundamental physical order it implies, we cannot solve a whole net of such problems so casually, and get away with it. It is inconceivable that we should succeed in organizing an ensemble as complex as the modern city until we have a clear enough view of simpler design problems and their implications to produce houses which are physically clear as total organizations.

Yet at present, in our own civilization, house forms which are clearly organized and also satisfactory in all the respects demanded by the context are almost unknown.

If we look at a peasant farmhouse by comparison, or at an igloo, or at an African's mud hut, this combination of good fit and clarity is not quite so hard to find. Take the Mousgoum hut, for instance, built by African tribesmen in the northern section of the French Cameroun.[5] Apart from the variation caused by slight changes in site and occupancy, the huts vary very little. Even superficial examination shows that they are all versions of the same single form type, and convey a powerful sense of their own adequacy and nonarbitrariness.

Whether by coincidence or not, the hemispherical shape of the hut provides the most efficient surface for minimum heat transfer, and keeps the inside reasonably well protected from the heat of the equatorial sun. Its shape is maintained by a series of vertical reinforcing ribs. Besides helping to support the main fabric, these ribs also act as guides for rainwater, and are at the same time used by the builder of the hut as footholds which give him access to the upper part of the outside during its construction.[6] Instead of using disposable scaffolding (wood is very scarce), he builds the scaffolding

in as part of the structure. What is more, months later this "scaffolding" is still there when the owner needs to climb up on it to repair the hut. The Mousgoum cannot afford, as we do, to regard maintenance as a nuisance which is best forgotten until it is time to call the local plumber. It is in the same hands as the building operation itself, and its exigencies are as likely to shape the form as those of the initial construction.

Again, each hut nestles beautifully in the dips and hollows of the terrain. It must, because its fabric is as weak structurally as the earth it sits on, and any foreignness or discontinuity caused by careless siting would not have survived the stresses of erosion. The weather-defying concrete foundations which we rely on, and which permit the arbitrary siting of our own houses, are unknown to the Mousgoum.

The grouping of the huts reflects the social order of their inhabitants. Each man's hut is surrounded by the huts of his wives and his subservients, as social customs require — and in such a way, moreover, that these subsidiary huts also form a wall round the chief's hut and thereby protect it and themselves from wild beasts and invaders.[7]

This example shows how the pattern of the building operation, the pattern of the building's maintenance, the constraints of the surrounding conditions, and also the pattern of daily life, are fused in the form. The form has a dual coherence. It is coherently related to its context. And it is physically coherent.

This kind of dual coherence is common in simple cultures. Yet in our own culture the only forms which match these simpler forms for overall clarity of conception are those we have already mentioned, designed under the impulse of very special preoccupations. And these forms, just because they derive their clarity from simplification of the problem, fail to meet all the context's demands.[8] It is true that our functional standards are higher than those in the simple situation. It is true, and important to remember, that the simple cultures never face the problems of complexity which we face in design. And it is true that if they did face them, they would probably not make any better a showing than we do.[9] When we admire the simple situation for its good qualities, this doesn't mean that we wish we were back in the same situation. The dream of innocence is of little comfort to us; our problem, the problem of organizing form under complex constraints, is new and all our own. But in their own way the simple cultures do their simple job better than we do ours. I believe that only careful examination of their success can give us the insight we need to solve the problem of complexity. Let us ask, therefore, where this success comes from.

To answer this question we shall first have to draw a sharp and arbitrary line between those cultures we want to call simple, for the purposes of argument, and those we wish to classify with ours. I propose calling certain cultures unselfconscious, to contrast them with others, including our own, which I propose to call selfconscious.

Of course, the contrast in quality between the forms produced in the two different kinds of culture is by no means as marked as I shall suggest. Nor are the two form-making processes sharply distinguished, as my text pretends. But I have deliberately exaggerated the contrast, simply to draw attention to certain matters, important and illuminating in their own right, which we must understand before we can map out a new approach to design. It is far more important

that we should understand the particular contrast I am trying to bring out, than that the facts about any given culture should be accurate or telling. This is not an anthropological treatise, and it is therefore best to think of the first part of the following discussion simply as a comparison of two descriptive constructs, the unselfconscious culture and the selfconscious culture.[10]

The cultures I choose to call "unselfconscious" have, in the past, been called by many other names — each name chosen to illuminate whatever aspect of the contrast between kinds of culture the writer was most anxious to bring out. Thus they have been called "primitive," to distinguish them from those where kinship plays a less important part in social structure;[11] "folk," to set them apart from urban cultures;[12] "closed," to draw attention to the responsibility of the individual in today's more open situation;[13] "anonymous," to distinguish them from cultures in which a profession called "architecture" exists.[14]

The particular distinction I wish to make touches only the last of these: the method of making things and buildings. Broadly, we may distinguish between our own culture, which is very selfconscious about its architecture, art, and engineering, and certain specimen cultures which are rather unselfconscious about theirs.[15] The features which distinguish architecturally unselfconscious cultures from selfconscious ones are easy to describe loosely. In the unselfconscious culture there is little thought about architecture or design as such. There is a right way to make buildings and a wrong way; but while there may be generally accepted remedies for specific failures, there are no general principles comparable to Alberti's treatises or Le Corbusier's. Since the division of labor is very limited, specialization of any sort is rare, there are no architects, and each man builds his own house.[16]

The technology of communication is underdeveloped. There are no written records or architectural drawings, and little intercultural exchange. This lack of written records and lack of information about other cultures and situations means that the same experience has to be won over and over again generation after generation — without opportunity for development or change. With no variety of experience, people have no chance to see their own actions as alternatives to other possibilities, and instead of becoming selfconscious, they simply repeat the patterns of tradition, because these are the only ones they can imagine. In a word, actions are governed by habit.[17] Design decisions are made more according to custom than according to any individual's new ideas. Indeed, there is little value attached to the individual's ideas as such. There is no special market for his inventiveness. Ritual and taboo discourage innovation and self-criticism. Besides, since there is no such thing as "architecture" or "design," and no abstractly formulated problems of design, the kinds of concept needed for architectural self-criticism are too poorly developed to make such self-criticism possible; indeed the architecture itself is hardly tangibly enough conceived as such to criticize.

To be sure that such a distinction between unselfconscious and selfconscious cultures is permissible, we need a definition which will tell us whether to call a culture unselfconscious or selfconscious on the basis of visible and reportable facts alone. We find a clearly visible distinction when we look at the way the crafts of form-building are taught and learned, the institutions under which skills pass from one generation to the next.

For there are essentially two ways in which such education can operate, and they may be distinguished without difficulty.

At one extreme we have a kind of teaching that relies on the novice's very gradual exposure to the craft in question, on his ability to imitate by practice, on his response to sanctions, penalties, and reinforcing smiles and frowns. The great example of this kind of learning is the child's learning of elementary skills, like bicycle riding. He topples almost randomly at first, but each time he does something wrong, it fails; when he happens to do it right, its success and the fact that his success is recognized make him more likely to repeat it right.[18] Extended learning of this kind gives him a "total" feeling for the thing learned — whether it is how to ride a bicycle, or a skill like swimming, or the craft of housebuilding or weaving. The most important feature of this kind of learning is that the rules are not made explicit, but are, as it were, revealed through the correction of mistakes.[19]

The second kind of teaching tries, in some degree, to make the rules explicit. Here the novice learns much more rapidly, on the basis of general "principles." The education becomes a formal one; it relies on instruction and on teachers who train their pupils, not just by pointing out mistakes, but by inculcating positive explicit rules. A good example is lifesaving, where people rarely have the chance to learn by trial and error. In the informal situation there are no "teachers," for the novice's mistakes will be corrected by anybody who knows more than he. But in the formal situation, where learning is a specialized activity and no longer happens automatically, there are distinct "teachers" from whom the craft is learned.[20]

These teachers, or instructors, have to condense the knowledge which was once laboriously acquired in experience, for without such condensation the teaching problem would be unwieldy and unmanageable. The teacher cannot refer explicitly to each single mistake which can be made, for even if there were time to do so, such a list could not be learned. A list needs a structure for mnemonic purposes.[21] So the teacher invents teachable rules within which he accommodates as much of his unconscious training as he can — a set of shorthand principles.

In the unselfconscious culture the same form is made over and over again; in order to learn form-making, people need only learn to repeat a single familiar physical pattern. In the selfconscious culture new purposes are occurring all the time; the people who make forms are constantly required to deal with problems that are either entirely new or at best modifications of old problems. Under these circumstances it is not enough to copy old physical patterns. So that people will be able to make innovations and modifications as required, ideas about how and why things get their shape must be introduced. Teaching must be based on explicit general principles of function, rather than unmentioned and specific principles of shape.

I shall call a culture unselfconscious if its form-making is learned informally, through imitation and correction. And I shall call a culture selfconscious if its form-making is taught academically, according to explicit rules.[22]

Now why are forms made in the selfconscious culture not so well fitting or so clearly made as those in the unselfconscious culture? In one case the form-making process is a good one, in the other bad. What is it that makes a form-making process good or bad?

In explaining why the unselfconscious process is a good one, hardly anyone bothers, nowadays, to argue the myth of the primitive genius, the unsophisticated craftsman supposedly more gifted than his sophisticated counterpart.[23] The myth of architectural Darwinism has taken its place.[24] Yet though this new myth is more acceptable, in its usual form it is not really any more informative than the other.

It says, roughly, that primitive forms are good as a result of a process of gradual adaptation — that over many centuries such forms have gradually been fitted to their cultures by an intermittent though persistent series of corrections. But this explanation is vague hand-waving.[25] It doesn't tell us what it is that prevents such adaptation from taking place successfully in the selfconscious culture, which is what we want to know most urgently. And even as an explanation of good fit in the unselfconscious culture, the raw concept of adaptation is something less than satisfactory. If forms in an unselfconscious culture fit now, the chances are that they always did. We know of no outstanding differences between the present states and past states of unselfconscious cultures; and this assumption, that the fit of forms in such cultures is the result of gradual adjustment (that is, improvement) over time, does not illuminate what must actually be a dynamic process in which both form and context change continuously, and yet stay mutually well adjusted all the time.[26]

To understand the nature of the form-making process, it is not enough to give a quick one-word account of unselfconscious form-making: adaptation. We shall have to compare the detailed inner working of the unselfconscious form-making process with that of the selfconscious process, asking why one works and the other fails. Roughly speaking, I shall argue that the unselfconscious process has a structure that makes it homeostatic (self-organizing), and that it therefore consistently produces well-fitting forms, even in the face of change. And I shall argue that in a selfconscious culture the homeostatic structure of the process is broken down, so that the production of forms which fail to fit their contexts is not only possible, but likely.[27]

We decided in the last chapter that to describe fit and misfit between form and context, we must make a list of binary variables, each naming some one potential misfit which may occur.

Whether a form-making process is selfconscious or unselfconscious, these misfit variables are always present, lingering in the background of the process, as thoughts in a designer's mind, or as actions, criticisms, failures, doubts. Only the thought or the experience of possible failure provides the impetus to make new form.

At any moment in a form-making process, whether the form is in use, a prototype, as yet only a sketch, or obsolete, each of the variables is in a state of either fit or misfit. We may describe the state of all the variables at once by a row of 1's and 0's, one for each variable: for instance, for twenty variables, 00100110101110110000 would be one state. Each possible row of 1's and 0's is a possible state of the ensemble.

As form-making proceeds, so the system of variables changes state. One misfit is eradicated, another misfit occurs, and these changes in their turn set off reactions within the system that affect the states of other variables. As form and culture change, state follows state. The sequence of states which the system

passes through is a record or history of the adaptation between form and context. The history of the system displays the form-making process at work. To compare unselfconscious and selfconscious form-making processes, we have only to examine the kinds of history which the system of variables can have in these two processes. As we shall see, the kinds of history which the system can have in the unselfconscious and selfconscious processes are very different.

We shall perhaps understand the idea of a system's history best if we make a simple picture of it.[28]

Imagine a system of a hundred lights. Each light can be in one of two possible states. In one state the light is on. The lights are so constructed that any light which is on always has a 50–50 chance of going off in the next second. In the other state the light is off. Connections between lights are constructed so that any light which is off has a 50–50 chance of going on again in the next second, provided at least one of the lights it is connected to is on. If the lights it is directly connected to are off, for the time being it has no chance of going on again, and stays off. If the lights are ever all off simultaneously, then they will all stay off for good, since when no light is on, none of the lights has any chance of being reactivated. This is a state of equilibrium. Sooner or later the system of lights will reach it.

This system of lights will help us understand the history of a form-making process. Each light is a binary variable, and so may be thought of as a misfit variable. The off state corresponds to fit; the on state corresponds to misfit. The fact that a light which is on has a 50–50 chance of going off every second, corresponds to the fact that whenever a misfit occurs efforts are made to correct it. The fact that lights which are off can be turned on again by connected lights, corresponds to the fact that even well-fitting aspects of a form can be unhinged by changes initiated to correct some other misfit because of connections between variables. The state of equilibrium, when all the lights are off, corresponds to perfect fit or adaptation. It is the equilibrium in which all the misfit variables take the value 0. Sooner or later the system of lights will always reach this equilibrium. The only question that remains is, how long will it take for this to happen? It is not hard to see that apart from chance this depends only on the pattern of interconnections between the lights.

Let us consider two extreme circumstances.[29]

1. On the one hand, suppose there are no interconnections between lights at all. In this case there is nothing to prevent each light's staying off for good, as soon as it goes off. The average time it takes for all the lights to go off is therefore only a little greater than the average time it takes for a single light to go off, namely 2^1 seconds or 2 seconds.

2. On the other hand, imagine such rich interconnections between lights that any one light still on quickly rouses all others from the off state and puts them on again. The only way in which this system can reach adaptation is by the pure chance that all 100 happen to go off at the same moment. The average time which must elapse before this happens will be of the order of 2^{100} seconds, or 10^{22} years.

The second case is useless. The age of the universe itself is only about 10^{10} years. For all intents and purposes the system will never adapt. But the first case is no use either. In any real system there are interconnections between variables which make it impossible for each variable to adapt in complete isolation. Let us therefore construct a third possibility.

3. In this case suppose there are again interconnections among the 100 lights, but that we discern in the pattern of interconnections some 10 principal subsystems, each containing 10 lights.[30] The lights within each subsystem are so strongly connected to one another that again all 10 must go off simultaneously before they will stay off; yet at the same time the subsystems themselves are independent of one another as wholes, so that the lights in one subsystem can be switched off without being reactivated by others flashing in other subsystems. The average time it will take for all 100 lights to go off is about the same as the time it takes for one subsystem to go off, namely 2^{10} seconds, or about a quarter of an hour.

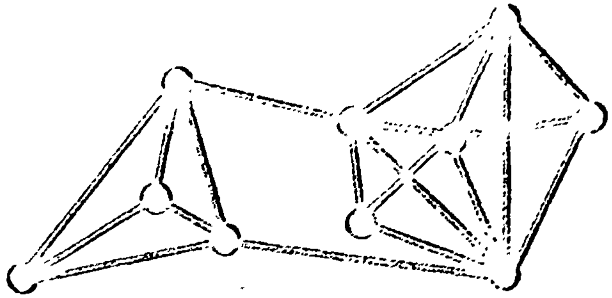
Of course, real systems do not behave so simply. But fifteen minutes is not much greater than the two seconds it takes an isolated variable to adapt, and the enormous gap between these magnitudes and 10^{22} years does teach us a vital lesson. No complex adaptive system will succeed in adapting in a reasonable amount of time unless the adaptation can proceed subsystem by subsystem, each subsystem relatively independent of the others.[31]

This is a familiar fact. It finds a close analogy in the children's sealed glass-fronted puzzles which are such fun and so infuriating. The problem, in these puzzles, is to achieve certain configurations within the box: rings on sticks, balls in sockets, pieces of various shapes in odd-shaped frames — but all to be done by gentle tapping on the outside of the box. Think of the simplest of these puzzles, where half a dozen colored beads, say, are each to be put in a hole of corresponding color.

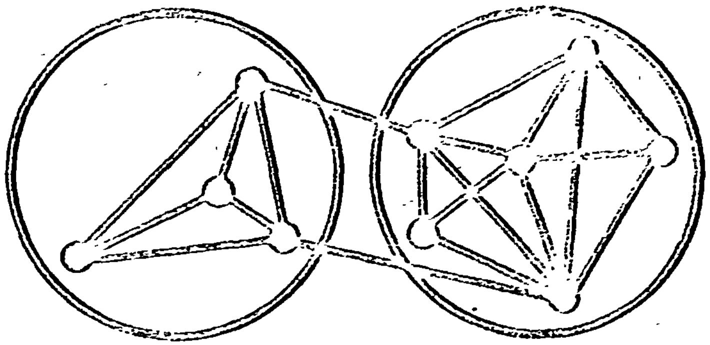
One way to go about this problem would be to pick the puzzle up, give it a single energetic shake, and lay it down again, in the hope that the correct configuration would appear by accident. This all-or-nothing method might be repeated many thousand times, but it is clear that its chances of success are negligible. It is the technique of a child who does not understand how best to play. Much the easiest way — and the way we do in fact adopt under such circumstances — is to juggle one bead at a time. Once a bead is in, provided we tap gently, it is in for good, and we are free to manipulate the next one that presents itself, and we achieve the full configuration step by step. When we treat each bead as an isolable subsystem, and take the subsystems independently, we can solve the puzzle.

If we now consider the process of form-making, in the light of these examples, we see an easy way to make explicit the distinction between processes which work and those which don't.

Let us remind ourselves of the precise sense in which there is a system active in a form-making process. It is a purely fictitious system. Its variables are the conditions which must be met by good fit between form and context. Its interactions are the causal linkages which connect the variables to one another. If there is not enough light in a house, for instance, and more windows are added to correct this failure, the change may improve the light but allow too little privacy; another change for more light makes the windows bigger, perhaps, but thereby makes the house more likely to collapse. These are examples of inter-variable linkage. If we represent this system by drawing a point for each misfit variable, and a link between two points for each such causal linkage, we get a structure which looks something like this:



Now, let us go back to the question of adaptation. Clearly these misfit variables, being interconnected, cannot adjust independently, one by one. On the other hand, since not all the variables are equally strongly connected (in other words there are not only dependences among the variables, but also *independences*), there will always be subsystems like those circled below, which can, in principle, operate fairly independently.[32]



We may therefore picture the process of form-making as the action of a series of subsystems, all interlinked, yet sufficiently free of one another to adjust independently in a feasible amount of time. It works, because the cycles of correction and recorrection, which occur during adaptation, are restricted to one subsystem at a time.

We shall not be able to see, directly, whether or not the unselfconscious and selfconscious form-making processes operate by subsystems. Instead we shall infer their modes of operation indirectly.

The greatest clue to the inner structure of any dynamic process lies in its reaction to change. A culture does not move from one change to the next in discrete steps, of course. New threads are being woven all the time, making changes continuous and smooth. But from the point of view of its effect on a form, change only becomes significant at that moment when a failure or misfit reaches critical importance — at that moment when it is recognized, and people feel the form has something wrong with it. It is therefore legitimate, for our purpose, to consider a culture as changing in discrete steps.[33]

We wish to know, now, how the form-making process reacts to one such change. Whether a new, previously unknown misfit occurs or a known one recurs, in both cases, from our point of view, some one variable changes value from 0 to 1. What, precisely, happens when a misfit variable takes the value 1? How does the process behave under this stimulus?

Let us go back for a moment to our system of 100 lights. Suppose the system is in a state of fit — that is, all the lights are switched off. Now imagine that every once in a while one light gets switched on by an outside agent, even though no others are on to activate it. By waiting to see what happens next, we can very easily deduce the inner nature of the system, even though we cannot see it directly. If the light always flashes just once, and then goes off again and stays off, we deduce that the lights are able to adapt independently, and hence that there are no interconnections between lights. If the light activates a few other lights, and they flash together for a while, and then switch themselves off, we deduce that there are subsystems of interconnected lights active. If the light flashes and then activates other lights until all of them are flashing, and they never settle down again, we deduce that the system is unable to adapt subsystem by subsystem because the interconnections are too rich.

The solitary light switched on by an external agent is the occasional misfit which occurs. The reaction of the system to the disturbance is the reaction of the form-making process to the misfit. If we detect the active presence of subsystems in a process, we may then argue (by induction, as it were) that this is fully responsible for the good fit of the forms being produced by the process. For if good forms can always be adjusted correctly the moment any slight misfit occurs, then no sequence of changes will destroy the good fit ever (at least while the process maintains this character); and provided there was good fit at some stage in the past, no matter how remote (the first term of the induction), it will have persisted, because there is an active stability at work.[34] If, on the other hand, a form-making process is such that a minor culture change can upset the good fit of the forms it produces, then any well-fitting forms we may observe at one time or another fit only by accident; and the next cultural deflection may once more lead to the production of badly fitting forms.

It is the inner nature of the process which counts. The vital point that underlies the following discussion is that the formbuilders in unselfconscious cultures respond to small changes in a way that allows the subsystems of the misfit system to work independently — but that because the selfconscious response to change cannot take place subsystem by subsystem, its forms are arbitrary.

4 / THE UNSELFCONSCIOUS PROCESS

Let us turn our attention, first of all, to the unselfconscious cultures. It will be necessary first to outline the conditions under which forms in unselfconscious cultures are produced. We know by definition that building skills are learned informally, without the help of formulated rules.[1] However, although there are no formulated rules (or perhaps indeed, as we shall see later, just because there are none), the unspoken rules are of great complexity, and are rigidly maintained. There is a way to do things, a way not to do them. There is a firmly set tradition, accepted beyond question by all builders of form, and this tradition strongly resists change.

The existence of such powerful traditions, and evidence of their rigidity, already are shown to some extent in those aspects of unselfconscious cultures which have been discussed. It is clear, for instance, that forms do not remain the same for centuries without traditions springing up about them. If the Egyptian houses of the Nile have the same plan now as the houses whose plans were pictured in the hieroglyphs,[2] we can be fairly certain that their makers are in the grip of a tradition. Anywhere where forms are virtually the same now as they were thousands of years ago, the bonds must be extremely strong. In southern Italy, neither the *trulli* of Apulia nor the coalburners' *capanne* of Anzio near Rome have

changed since prehistoric times.[3] The same is known to be true of the black houses of the Outer Hebrides, and of the hogans of the Navaho.[4]

The most visible feature of architectural tradition in such unselfconscious cultures is the wealth of myth and legend attached to building habits. While the stories rarely deal exclusively with dwellings, nevertheless descriptions of the house, its form, its origins, are woven into many of the global myths which lie at the very root of culture; and wherever this occurs, not only is the architectural tradition made unassailable, but its constant repetition is assured. The black tents, for example, common among nomads from Tunisia to Afghanistan, figure more than once in the Old Testament.[5] In a similar way the folk tales of old Ireland and the Outer Hebrides are full of oblique references to the shape of houses.[6] The age of these examples gives us an inkling of the age and strength of the traditions which maintain the shape of unselfconscious dwelling forms. Wherever the house is mentioned in a myth or lore, it at once becomes part of the higher order, ineffable, immutable, not to be changed. When certain Indians of the Amazon believe that after death the soul retires to a house at the source of a mysterious river,[7] the mere association of the house with a story of this kind discourages all thoughtful criticism of the standard form, and sets its "rightness" well beyond the bounds of question.

More forceful still, of course, are rituals and taboos connected with the dwelling. Throughout Polynesia the resistance to change makes itself felt quite unequivocally in the fact that the building of a house is a ceremonial occasion.[8] The performance of the priests, and of the workers, though different from one island to the next, is always clearly specified; and the rigidity of these behavior patterns, by preserving techniques, preserves the forms themselves and makes change extremely difficult. The Navaho Indians, too, make their hogans the center of the most elaborate performance.[9] Again the gravity of the rituals, and their rigidity, make it impossible that the form of the hogan should be lightly changed.

The rigidity of tradition is at its clearest, though, in the case where builders of form are forced to work within definitely given limitations. The Samoan, if he is to make a good house, must use wood from the breadfruit tree.[10] The Italian peasant making his *trullo* at Alberobello is allowed latitude for individual expression only in the lump of plaster which crowns the cone of the roof.[11] The Wanoe has a chant which tells him precisely the sequence of operations he is to follow while building his house.[12] The Welshman must make the crucks which support his roof precisely according to the pattern of tradition.[13] The Sumatran gives his roofs their special shape, not because this is structurally essential, but because this is the way to make roofs in Sumatra.[14]

Every one of these examples points in the same direction. Unselfconscious cultures contain, as a feature of their form-producing systems, a certain built-in fixity — patterns of myth, tradition, and taboo which resist willful change. Form-builders will only introduce changes under strong compulsion where there are powerful (and obvious) irritations in the existing forms which demand correction.

Now when there are such irritations, how fast does the failure lead to action, how quickly does it lead to a change of form? Think first, perhaps, of man's closeness to the ground in the unselfconscious culture, and of the materials he uses when

he makes his house. The Hebridean crofter uses stone and clay and sods and grass and straw, all from the near surroundings.[15] The Indian's tent used to be made of hide from the buffalo he ate.[16] The Apulian uses as building stones the very rocks which he has taken from the ground to make his agriculture possible.[17] These men have a highly developed eye for the trees and stones and animals which contain the means of their livelihood, their food, their medicine, their furniture, their tools. To an African tribesman the materials available are not simply objects, but are full of life.[18] He knows them through and through; and they are always close to hand.

Closely associated with this immediacy is the fact that the owner is his own builder, that the form-maker not only makes the form but lives in it. Indeed, not only is the man who lives in the form the one who made it, but there is a special closeness of contact between man and form which leads to constant rearrangement of unsatisfactory detail, constant improvement. The man, already responsible for the original shaping of the form, is also alive to its demands while he inhabits it.[19] And anything which needs to be changed is changed at once.

The Abipon, whose dwelling was the simplest tent made of two poles and a mat, dug a trench to carry off the rain if it bothered him.[20] The Eskimo reacts constantly to every change in temperature inside the igloo by opening holes or closing them with lumps of snow.[21] The very special directness of these actions may be made clearer, possibly, as follows. Think of the moment when the melting snow dripping from the roof is no longer bearable, and the man goes to do something about it. He makes a hole which lets some cold air in, perhaps. The man realizes that he has to do something about it — but he does not do so by remembering the general rule and then applying it ("When the snow starts to melt it is too hot inside the igloo and therefore time to . . ."). He simply does it. And though words may accompany his action, they play no essential part in it. This is the important point. The failure or inadequacy of the form leads directly to the action.

This directness is the second crucial feature of the unselfconscious system's form-production. Failure and correction go side by side. There is no deliberation in between the recognition of a failure and the reaction to it.[22] The directness is enhanced, too, by the fact that building and repair are so much an everyday affair. The Eskimo, on winter hunts, makes a new igloo every night.[23] The Indian's tepee cover rarely lasts more than a single season.[24] The mud walls of the Tallensi hut need frequent daubs.[25] Even the elaborate communal dwellings of the Amazon tribes are abandoned every two or three years, and new ones built.[26] Impermanent materials and unsettled ways of life demand constant reconstruction and repair, with the result that the shaping of form is a task perpetually before the dweller's eyes and hands. If a form is made the same way several times over, or even simply left unchanged, we can be fairly sure that its inhabitant finds little wrong with it. Since its materials are close to hand, and their use his own responsibility, he will not hesitate to act if there are any minor changes which seem worth making.

Let us return now to the question of adaptation. The basic principle of adaptation depends on the simple fact that the process toward equilibrium is irreversible. Misfit provides an incentive to change; good fit provides none. In theory the process is eventually bound to reach the equilibrium of well-fitting forms.

However, for the fit to occur in practice, one vital condition must be satisfied. It must have time to happen. The process must be able to achieve its equilibrium before the next culture change upsets it again. It must actually have time to reach its equilibrium every time it is disturbed — or, if we see the process as continuous rather than intermittent, the adjustment of forms must proceed more quickly than the drift of the culture context. Unless this condition is fulfilled the system can never produce well-fitting forms, for the equilibrium of the adaptation will not be sustained.

As we saw in Chapter 3, the speed of adaptation depends essentially on whether the adaptation can take place in independent and restricted subsystems, or not. Although we cannot actually see these subsystems in the unselfconscious process, we can infer their activity from the very two characteristics of the process which we have been discussing: directness and tradition.

The direct response is the feedback of the process.[27] If the process is to maintain the good fit of dwelling forms while the culture drifts, it needs a feedback sensitive enough to take action the moment that one of the potential failures actually occurs. The vital feature of the feedback is its immediacy. For only through prompt action can it prevent the build-up of multiple failures which would then demand simultaneous correction — a task which might, as we have seen, take too long to be feasible in practice.

However, the sensitivity of feedback is not ~~in~~ itself enough to lead to equilibrium. The feedback must be controlled, or damped, somehow.[28] Such control is provided by the resistance to change the unselfconscious culture has built into its traditions. We might say of these traditions, possibly, that they make the system viscous. This viscosity damps the changes made, and prevents their extension to other aspects of the form. As a result only urgent changes are allowed. Once a form fits well, changes are not made again until it fails to fit again. Without this action of tradition, the repercussions and ripples started by the slightest failure could grow wider and wider until they were spreading too fast to be corrected.

On the one hand the directness of the response to misfit ensures that each failure is corrected as soon as it occurs, and thereby restricts the change to one subsystem at a time. And on the other hand the force of tradition, by resisting needless change, holds steady all the variables not in the relevant subsystem, and prevents those minor disturbances outside the subsystem from taking hold. Rigid tradition and immediate action may seem contradictory. But it is the very contrast between these two which makes the process self-adjusting. It is just the fast reaction to single failures, complemented by resistance to all other change, which allows the process to make series of minor adjustments instead of spasmodic global ones: it is able to adjust subsystem by subsystem, so that the process of adjustment is faster than the rate at which the culture changes; equilibrium is certain to be re-established whenever slight disturbances occur; and the forms are not simply well-fitted to their cultures, but in active equilibrium with them.[29]

The operation of such a process hardly taxes the individual craftsman's ability at all. The man who makes the form is an agent simply, and very little is required of him during the form's development. Even the most aimless changes will eventually lead to well-fitting forms, because of the tendency to equilibrium inherent in the organization of the process.

All the agent need do is to recognize failures when they occur, and to react to them. And this even the simplest man can do. For although only few men have sufficient integrative ability to invent form of any clarity, we are all able to criticize existing forms.[30] It is especially important to understand that the agent in such a process needs no creative strength. He does not need to be able to improve the form, only to make some sort of change when he notices a failure. The changes may not be always for the better; but it is not necessary that they should be, since the operation of the process allows only the improvements to persist.

To make the foregoing analysis quite clear, I shall use it to illuminate a rather curious phenomenon.[31] The Slovakian peasants used to be famous for the shawls they made. These shawls were wonderfully colored and patterned, woven of yarns which had been dipped in homemade dyes. Early in the twentieth century aniline dyes were made available to them. And at once the glory of the shawls was spoiled; they were now no longer delicate and subtle, but crude. This change cannot have come about because the new dyes were somehow inferior. They were as brilliant, and the variety of colors was much greater than before. Yet somehow the new shawls turned out vulgar and uninteresting.

Now if, as it is so pleasant to suppose, the shawlmakers had had some innate artistry, had been so gifted that they were simply "able" to make beautiful shawls, it would be almost impossible to explain their later clumsiness. But if we look at the situation differently, it is very easy to explain. The shawlmakers were simply able, as many of us are, to recognize *bad* shawls, and their own mistakes.

Over the generations the shawls had doubtless often been made extremely badly. But whenever a bad one was made, it was recognized as such, and therefore not repeated. And though nothing is to say that the change made would be for the better, it would still be a change. When the results of such changes were still bad, further changes would be made. The changes would go on until the shawls were good. And only at this point would the incentive to go on changing the patterns disappear.

So we do not need to pretend that these craftsmen had special ability. They made beautiful shawls by standing in a long tradition, and by making minor changes whenever something seemed to need improvement. But once presented with more complicated choices, their apparent mastery and judgment disappeared. Faced with the complex unfamiliar task of actually inventing forms from scratch, they were unsuccessful.

5 / THE SELFCONSCIOUS PROCESS

In the unselfconscious culture a clear pattern has emerged. Being self-adjusting, its action allows the production of well-fitting forms to persist in active equilibrium with the system.

The way forms are made in the selfconscious culture is very different. I shall try to show how, just as it is a property of the unselfconscious system's organization that it produces well-fitting forms, so it is a property of the emergent selfconscious system that its forms fit badly.

In one way it is easy enough to see what goes wrong with the arrival of selfconsciousness. The very features which we have found responsible for stability in the unselfconscious process begin to disappear.

The reaction to failure, once so direct, now becomes less and less direct. Materials are no longer close to hand. Buildings are more permanent, frequent repair and readjustment less common, than they used to be. Construction is no longer in the hands of the inhabitants; failures, when they occur, have to be several times reported and described before the specialist will recognize them and make some permanent adjustment. Each of these changes blunts the hair-fine sensitivity of the unselfconscious process' response to failure, so that failures now need to be quite considerable before they will induce correction.

The firmness of tradition too, dissolves. The resistance to willful change weakens, and change for its own sake becomes acceptable. Instead of forms being held constant in all respects but one, so that correction can be immediately effective, the interplay of simultaneous changes is now uncontrolled. To put it playfully, the viscosity which brought the unselfconscious process to rest when there were no failures left, is thinned by the high temperature of selfconsciousness. And as a result the system's drive to equilibrium is no longer irreversible; any equilibrium the system finds will not now be sustained; those aspects of the process which could sustain it have dropped away.

In any case, the culture that once was slow-moving, and allowed ample time for adaptation, now changes so rapidly that adaptation cannot keep up with it. No sooner is adjustment of one kind begun than the culture takes a further turn and forces the adjustment in a new direction. No adjustment is ever finished. And the essential condition on the process — that it should in fact have time to reach its equilibrium — is violated.

This has all actually happened. In our own civilization, the process of adaptation and selection which we have seen at work in unselfconscious cultures has plainly disappeared. But that is not in itself enough to account for the fact that the selfconscious culture does not manage to produce clearly organized, well-fitting forms in its own way. Though we may easily be right in putting our present unsuccess down to our selfconsciousness, we must find out just what it is about selfconscious form-production that causes trouble. The pathology of the selfconscious culture is puzzling in its own right, and is not to be explained simply by the passing of the unselfconscious process.

I do not wish to imply here that there is any unique process of development that makes selfconscious cultures out of unselfconscious ones. Let us remember anyway that the distinction between the two is artificial. And, besides, the facts of history suggest that the development from one to the other can happen in rather different ways.[1] From the point of view of my present argument it is immaterial how the development occurs. All that matters, actually, is that sooner or later the phenomenon of the master craftsman takes control of the form-making activities.

One example, of an early kind, of developing selfconsciousness is found in Samoa. Although ordinary Samoan houses are built by their inhabitants-to-be, custom demands that guest houses be built exclusively by carpenters.[2] Since these carpenters need to find clients, they are in business as artists; and they begin to make personal innovations and changes for no reason except that prospective clients will judge their work for its inventiveness.[3]

The form-maker's assertion of his individuality is an important feature of selfconsciousness. Think of the willful forms of our own limelight-bound architects. The individual, since his livelihood depends on the reputation he achieves, is anxious to distinguish himself from his fellow architects, to make innovations, and to be a star.[4]

The development of architectural individualism is the clearest manifestation of the moment when architecture first turns into a selfconscious discipline. And the selfconscious architect's individualism is not entirely willful either. It is a natural consequence of a man's decision to devote his life exclusively to the one activity called "architecture."[5] Clearly it is at this stage too that the activity first becomes ripe for serious thought and theory. Then, with architecture once established as a discipline, and the individual architect established, entire institutions are soon devoted exclusively to the study and development of design. The academies are formed. As the academies develop, the unformulated precepts of tradition give way to clearly formulated concepts whose very formulation invites criticism and debate.[6] Question leads to unrest, architectural freedom to further selfconsciousness, until it turns out that (for the moment anyway) the form-maker's freedom has been dearly bought. For the discovery of architecture as an independent discipline costs the form-making process many fundamental changes. Indeed, in the sense I shall now try to describe, architecture did actually fail from the very moment of its inception. With the invention of a teachable discipline called "architecture," the old process of making form was adulterated and its chances of success destroyed.

The source of this trouble lies with the individual. In the unselfconscious system the individual is no more than an agent.[7] He does what he knows how to do as best he can. Very little demand is made of him. He need not himself be able to invent forms at all. All that is required is that he should recognize misfits ~~and respond to them~~ by making minor changes. It is not even necessary that these changes be for the better. As we have seen, the system, being self-adjusting, finds its own equilibrium — provided only that misfit incites *some* reaction in the craftsman. The forms produced in such a system are not the work of individuals, and

their success does not depend on any one man's artistry, but only on the artist's place within the process.[8]

The selfconscious process is different. The artist's selfconscious recognition of his individuality has deep effect on the process of form-making. Each form is now seen as the work of a single man, and its success is his achievement only. Selfconsciousness brings with it the desire to break loose, the taste for individual expression, the escape from tradition and taboo, the will to self-determination. But the wildness of the desire is tempered by man's limited invention. To achieve in a few hours at the drawing board what once took centuries of adaptation and development, to invent a form suddenly which clearly fits its context — the extent of the invention necessary is beyond the average designer.

A man who sets out to achieve this adaptation in a single leap is not unlike the child who shakes his glass-topped puzzle fretfully, expecting at one shake to arrange the bits inside correctly.[9] The designer's attempt is hardly random as the child's is; but the difficulties are the same. *His chances of success are small because the number of factors which must fall simultaneously into place is so enormous.*

Now, in a sense, the limited capacity of the individual designer makes further treatment of the failure of selfconsciousness superfluous. If the selfconscious culture relies on the individual to produce its forms, and the individual isn't up to it, there seems nothing more to say. But it is not so simple. The individual is not merely weak. The moment he becomes aware of his own weakness in the face of the enormous challenge of a new design problem, he takes steps to overcome his weakness; and strangely enough these steps themselves exert a very positive bad influence on the way he develops forms. In fact, we shall see that the selfconscious system's lack of success really doesn't lie so much in the individual's lack of capacity as in the kind of efforts he makes, when he is selfconscious, to overcome this incapacity.

Let us look again at just what kind of difficulty the designer faces. Take, for example, the design of a simple kettle. He has to invent a kettle which fits the context of its use. It must not be too small. It must not be hard to pick up when it is hot. It must not be easy to let go of by mistake. It must not be hard to store in the kitchen. It must not be hard to get the water out of. It must pour cleanly. It must not let the water in it cool too quickly. The material it is made of must not cost too much. It must be able to withstand the temperature of boiling water. It must not be too hard to clean on the outside. It must not be a shape which is too hard to machine. It must not be a shape which is unsuitable for whatever reasonably priced metal it is made of. It must not be too hard to assemble, since this costs man-hours of labor. It must not corrode in steamy kitchens. Its inside must not be too difficult to keep free of scale. It must not be hard to fill with water. It must not be uneconomical to heat small quantities of water in, when it is not full. It must not appeal to such a minority that it cannot be manufactured in an appropriate way because of its small demand. It must not be so tricky to hold that accidents occur when children or invalids try to use it. It must not be able to boil dry and burn out without warning. It must not be unstable on the stove while it is boiling.

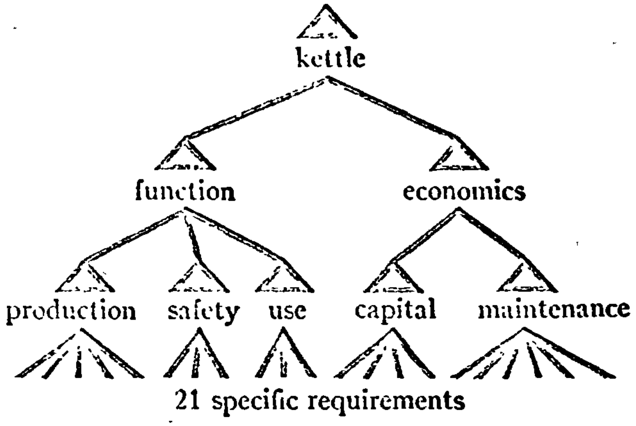
I have deliberately filled a page with the list of these twenty-one detailed requirements or misfit variables so as to

bring home the amorphous nature of design problems as they present themselves to the designer. Naturally the design of a complex object like a motor car is much more difficult and requires a much longer list. It is hardly necessary to speculate as to the length and apparent disorder of a list which could adequately define the problem of designing a complete urban environment.

How is a designer to deal with this highly amorphous and diffuse condition of the problem as it confronts him? What would any of us do?

Since we cannot refer to the list in full each time we think about the problem, we invent a shorthand notation. We classify the items, and then think about the names of the classes: since there are fewer of these, we can think about them much more easily. To put it in the language of psychology, there are limits on the number of distinct concepts which we can manipulate cognitively at any one time, and we are therefore forced, if we wish to get a view of the whole problem, to re-encode these items.[10] Thus, in the case of the kettle, we might think about the class of requirements generated by the process of the kettle's manufacture, its capacity, its safety requirements, the economics of heating water, and its good looks. Each of these concepts is a general name for a number of the specific requirements. If we were in a very great hurry (or for some reason wanted to simplify the problem even further), we might even classify these concepts in turn, and deal with the problem simply in terms of (1) its function and (2) its economics. In this case we would have erected a four-level hierarchy like that in the diagram on the next page.

By erecting such a hierarchy of concepts for himself, the



designer is, after all, able to face the problem all at once. He achieves a powerful economy of thought, and can by this means thread his way through far more difficult problems than he could cope with otherwise. If hierarchies seem less common in practice than I seem to suggest, we have only to look at the contents of any engineering manual or architects' catalogue; the hierarchy of chapter headings and subheadings is organized the way it is, precisely for cognitive convenience.[11]

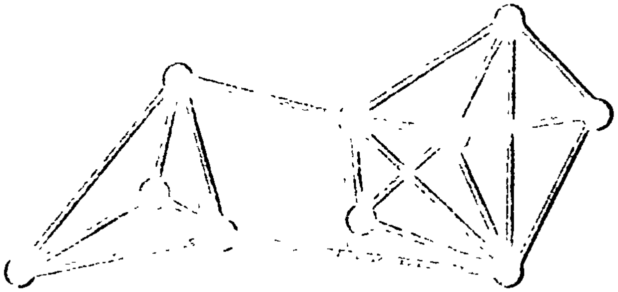
To help himself overcome the difficulties of complexity, the designer tries to organize his problem. He classifies its various aspects, thereby gives it shape, and makes it easier to handle. What bothers him is not only the difficulty of the problem either. The constant burden of decision which he comes across, once freed from tradition, is a tiring one. So he avoids it where he can by using rules (or general principles), which he formulates in terms of his invented concepts. These principles are at the root of all so-called "theories" of architectural design.[12] They are prescriptions which relieve the burden of selfconsciousness and of too much responsibility.

It is rash, perhaps, to call the invention of either concepts or prescriptions a conscious attempt to simplify problems. In practice they unfold as the natural outcome of critical discussion about design. In other words, the generation of verbal concepts and rules need not only be seen abstractly as the supposed result of the individual's predicament, but may be observed wherever the kind of formal education we have called selfconscious occurs.

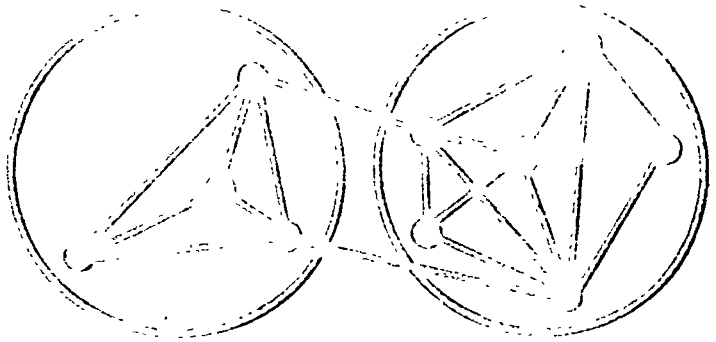
A novice in the unselfconscious situation learns by being put right whenever he goes wrong. "No, not that way, this way." No attempt is made to formulate abstractly just what the right way involves. The right way is the residue when all the wrong ways are eradicated. But in an intellectual atmosphere free from the inhibition of tradition, the picture changes. The moment the student is free to question what he is told, and value is put on explanation, it becomes important to decide why "this" is the right way rather than "that," and to look for general reasons. Attempts are made to aggregate the specific failures and successes which occur, into principles. And each such general principle now takes the place of many separate and specific admonitions. It tells us to avoid this kind of form, perhaps, or praises that kind. With failure and success defined, the training of the architect develops rapidly. The huge list of specific misfits which can occur, too complex for the student to absorb abstractly and for that reason usually to be grasped only through direct experience, as it is in the unselfconscious culture, *can* now be learned — because it has been given form. The misfit variables are patterned into categories like "economics" or "acoustics." And condensed, like this, they can be taught, discussed, and criticized. It is this point, where these concept-determined principles been taken in the training and practice of the architect, that the ill effect of selfconsciousness on form begins to show itself.

I shall now try to draw attention to the peculiar and damaging arbitrariness of the concepts which are invented. Let us remember that the system of interdependent requirements or misfit variables active in the unselfconscious ensemble is still present underneath the surface.

Suppose, as before, we picture the system crudely by drawing a link between every pair of interdependent requirements: we get something that looks like this.



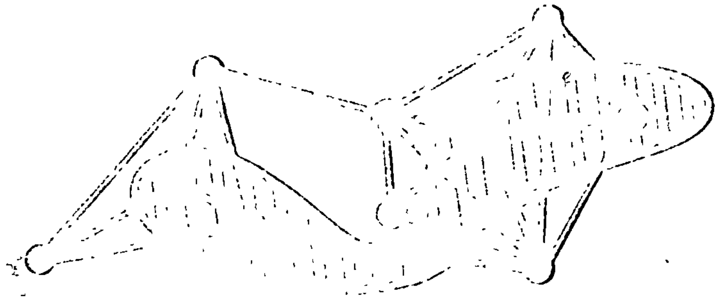
As we have seen before, the variables of such a system can be adjusted to meet the specified conditions in a reasonable time only if its subsystems are adjusted independently of one another. A subsystem, roughly speaking, is one of the obvious components of the system, like the parts shown with a circle round them. If we try to adjust a set of variables which does not constitute a subsystem, the repercussions of the adjustment affect others outside the set, because the set is not sufficiently independent. What we saw in Chapter 4, effectively, was that the procedure of the unselfconscious system is so



organized that adjustment *can* take place in each one of these subsystems independently. This is the reason for its success.

In the selfconscious situation, on the other hand, the designer is faced with all the variables simultaneously. Yet we know from the simple computation on page 19 that if he tries to manipulate them all at once he will not manage to find a well-fitting form in any reasonable time. When he himself senses this difficulty, he tries to break the problem down, and so invents concepts to help himself decide which subsets of requirements to deal with independently. Now what are these concepts, in terms of the system of variables? Each concept identifies a certain collection of the variables. "Economics" identifies one part of the system, "safety" another, "acoustics" another, and so on.

My contention is this. These concepts will not help the designer in finding a well-adapted solution unless they happen to correspond to the system's subsystems. But since the concepts are on the whole the result of arbitrary historical accidents, there is no reason to expect that they will in fact correspond to these subsystems. They are just as likely to identify any other parts of the system, like this:



Of course this demonstrates only that concepts *can* easily be arbitrary. It does not show that the concepts used in practice actually are so. Indeed, clearly, their arbitrariness can only be established for individual and specific cases. Detailed analysis of the problem of designing urban family houses, for instance, has shown that the usually accepted functional categories like acoustics, circulation, and accommodation are inappropriate for this problem.[13] Similarly, the principle of the "neighborhood," one of the old chestnuts of city-planning theory, has been shown to be an inadequate mental component of the residential planning problem.[14] But since such demonstrations can only be made for special cases, let us examine a more general, rather plausible reason for believing that such verbal concepts always will be of this arbitrary kind.

Every concept can be defined and understood in two complementary ways. We may think of it as the name of a class of objects or subsidiary concepts; or we may think of what it means. We define a concept *in extension* when we specify all the elements of the class it refers to. And we define a concept *in intension* when we try to explain its meaning analytically in terms of other concepts at the same level.[15]

For the sake of argument I have just been treating terms like "acoustics" as class names, as a collective way of talking about a number of more specific requirements. The "neighborhood," too, though less abstract and more physical, is still a concept which summarizes mentally all those specific requirements, like primary schooling, pedestrian safety, and community, which a physical neighborhood is supposed to meet. In other words, each of the concepts "acoustics" and "neighborhood" is a variable whose value extension is the same as that given by the conjunction of all the value extensions of the specific acoustic variables, or the specific community-living variables, respectively.[16] This extensional view of the concept is convenient for the sake of mathematical clarity. But in practice, as a rule, concepts are not generated or defined in extension; they are generated in intension. That is, we fit new concepts into the pattern of everyday language by relating their meanings to those of other words at present available in English.

Yet this part played by language in the invention of new concepts, though very important from the point of view of communication and understanding, is almost entirely irrelevant from the point of view of a problem's structure.[17] The demand that a new concept be definable and comprehensible is important from the point of view of teaching and self-conscious design. Take the concept "safety," for example. Its existence as a common word is convenient and helps hammer home the very general importance of keeping designs danger-free. But it is used in the statement of such dissimilar problems as the design of a tea kettle and the design of a highway interchange. As far as its meaning is concerned it is relevant to both. But as far as the individual structure of the two problems goes, it seems unlikely that the one word should successfully identify a principal component subsystem in each of these two very dissimilar problems. Unfortunately, although every problem has its own structure, and there are many different problems, the words we have available to describe the components of these problems are generated by forces in the language, not by the problems, and are therefore rather limited in number and cannot describe more than a few cases correctly.[18]

Take the simple problem of the kettle. I have listed 21 requirements which must take values within specified limits in an acceptably designed kettle. Given a set of n things, there are 2^n different subsets of these things. This means that there are 2^{21} distinct subsets of variables any one of which may possibly be an important component subsystem of the kettle problem. To name each of these components alone we should already need more than a million different words — more than there are in the English language.

A designer may object that his thinking is never as verbal as I have implied, and that, instead of using verbal concepts, he prepares himself for a complicated problem by making diagrams of its various aspects. This is true. Let us remember, however, just what things a designer tries to diagram. Physical concepts like "neighborhood" or "circulation pattern" have no more universal validity than verbal concepts. They are still bound by the conceptual habits of the draftsman. A typical sequence of diagrams which precede an architectural problem will include a circulation diagram, a diagram of acoustics, a diagram of the load-bearing structure, a diagram of sun and wind perhaps, a diagram of the social neighborhoods. I maintain that these diagrams are used only because the principles which define them — acoustics, circulation, weather, neighborhood — happen to be part of current architectural usage, not because they bear a well understood fundamental relation to any particular problem being investigated.[19]

As it stands, the selfconscious design procedure provides no structural correspondence between the problem and the means devised for solving it. The complexity of the problem is never fully disentangled, and the forms produced not only fail to meet their specifications as fully as they should, but also lack the formal clarity which they would have if the organization of the problem they are fitted to were better understood.

It is perhaps worth adding, as a footnote, a slightly different angle on the same difficulty. The arbitrariness of the existing verbal concepts is not their only disadvantage, for once they are invented, verbal concepts have a further ill-effect on us. We lose the ability to modify them. In the unselfconscious situation the action of culture on form is a very subtle business, made up of many minute concrete influences. But once these concrete influences are represented symbolically in verbal terms, and these symbolic representations or names subsumed under larger and still more abstract categories to make them amenable to thought, they begin seriously to impair our ability to see beyond them.[20]

Where a number of issues are being taken into account in a design decision, inevitably the ones which can be most clearly expressed carry the greatest weight, and are best reflected in the form. Other factors, important too but less well expressed, are not so well reflected. Caught in a net of language of our own invention, we overestimate the language's impartiality. Each concept, at the time of its invention no more than a concise way of grasping many issues, quickly becomes a precept. We take the step from description to criterion too easily, so that what is at first a useful tool becomes a bigoted preoccupation.

The Roman bias toward functionalism and engineering did not reach its peak until after Vitruvius had formulated the functionalist doctrine.[21] The Parthenon could only have been created during a time of preoccupation with aesthetic problems, after the earlier Greek invention of the concept "beauty." England's nineteenth century low-cost slums were conceived only after monetary values had explicitly been given great importance through the concept "economics," invented not long before.[22]

In this fashion the selfconscious individual's grasp of problems is constantly misled. His concepts and categories, besides being arbitrary and unsuitable, are self-perpetuating. Under the influence of concepts, he not only does things from a biased point of view, but sees them biasedly as well. The concepts control his perception of fit and misfit — until in the end he sees nothing but deviations from his conceptual dogmas, and loses not only the urge but even the mental opportunity to frame his problems more appropriately.

PART TWO

6 / THE PROGRAM

Here is the problem. We wish to design clearly conceived forms which are well adapted to some given context. We have seen that for this to be feasible, the adaptation must take place independently within independent subsystems of variables. In the unselfconscious situation this occurs automatically, because the individual craftsman has too little control over the process to upset the pattern of adaptation implicit in the ensemble. Unfortunately this situation no longer exists; the number of variables has increased, the information confronting us is profuse and confusing, and our attempts to duplicate the natural organization of the unselfconscious process selfconsciously are thwarted, because the very thoughts we have, as we try to help ourselves, distort the problem and make it too unclear to solve.

The dilemma is simple. As time goes on the designer gets more and more control over the process of design. But as he does so, his efforts to deal with the increasing cognitive burden actually make it harder and harder for the real causal structure of the problem to express itself in this process.

What can we do to overcome this difficulty? On the face of it, it is hard to see how any systematic theory can ease it much. There are certain kinds of problems, like some of those that occur in economics, checkers, logic, or administration, which can be clarified and solved mechanically.[1] They can be solved mechanically, because they are well enough understood for us to turn them into selection problems.[2]

To solve a problem by selection, two things are necessary.

1. It must be possible to generate a wide enough range of possible alternative solutions symbolically.
2. It must be possible to express all the criteria for solution in terms of the same symbolism.

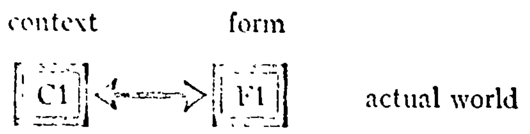
Whenever these two conditions are met, we may compare symbolically generated alternatives with one another by testing them against the criteria, until we find one which is satisfactory, or the one which is the best. It is at once obvious that wherever this kind of process is possible, we do not need to "design" a solution. Indeed, we might almost claim that a problem only calls for design (in the widest sense of that word) when selection cannot be used to solve it. Whether we accept this or not, the converse anyway is true. Those problems of creating form that are traditionally called "design problems" all demand invention.

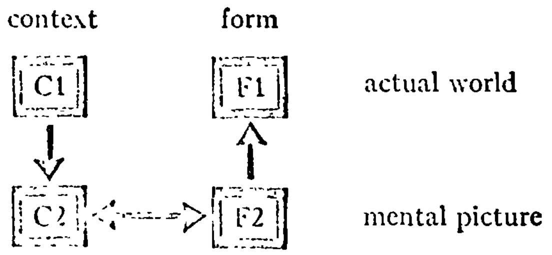
Let us see why this is so. First of all, for physical forms, we know no general symbolic way of generating new alternatives — or rather, those alternatives which we can generate by varying the existing types do not exhibit the radically new organization that solutions to new design problems demand. These can only be created by invention. Second, what is perhaps more important, we do not know how to express the criteria for success in terms of any symbolic description of a form. In other words, given a new design, there is often no

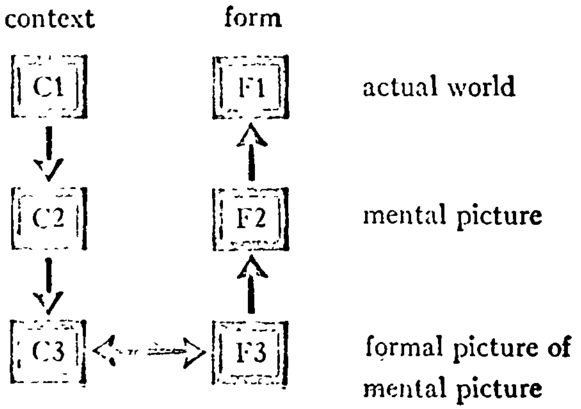
mechanical way of telling, purely from the drawings which describe it, whether or not it meets its requirements. Either we must put the real thing in the actual world, and see whether it works or not, or we must use our imagination and experience of the world to predict from the drawings whether it will work or not. But there is no general symbolic connection between the requirements and the form's description which provide criteria; and so there is no way of testing the form symbolically.[3] Third, even if these first two objections could be overcome somehow, there is a much more conclusive difficulty. This is the same difficulty, precisely, that we come across in trying to construct scientific hypotheses from a given body of data. The data alone are not enough to define a hypothesis; the construction of hypotheses demands the further introduction of principles like simplicity (Occam's razor), non-arbitrariness, and clear organization.[4] The construction of form, too, requires these principles. There is at present no prospect of introducing these principles mechanically, either into science or into design. Again, they require invention.

It is therefore not possible to replace the actions of a trained designer by mechanically computed decisions. Yet at the same time the individual designer's inventive capacity is too limited for him to solve design problems successfully entirely by himself. If theory cannot be expected to invent form, how is it likely to be useful to a designer?

Let us begin by stating rather more explicitly just what part the designer does play in the process of design. I shall contrast three possible kinds of design process, schematically.







The first scheme represents the unselfconscious situation described in Chapter 4. Here the process which shapes the form is a complex two-directional interaction between the context C1 and the form F1, in the world itself. The human being is only present as an agent in this process. He reacts to misfits by changing them; but is unlikely to impose any "designed" conception on the form.

The second scheme represents the selfconscious situation described in Chapter 5. Here the design process is remote from the ensemble itself; form is shaped not by interaction between the actual context's demands and the actual inadequacies of the form, but by a conceptual interaction between the conceptual picture of the context which the designer has learned and invented, on the one hand, and ideas and diagrams and drawings which stand for forms, on the other. This interaction contains both the probing in which the designer searches the problem for its major "issues," and the development of forms which satisfy them; but its exact nature is unclear.[5] In present design practice, this critical step, during which the problem is prepared and translated into design, always depends on some kind of intuition. Though design is by nature imaginative and intuitive, and we could easily trust it if the designer's intuition were reliable, as it is it inspires very little confidence.

In the unselfconscious process there is no possibility of misconstruing the situation: nobody makes a picture of the context, so the picture cannot be wrong. But the selfconscious designer works entirely from the picture in his mind, and this picture is almost always wrong.

The way to improve this is to make a further abstract picture of our first picture of the problem, which eradicates its bias and retains only its abstract structural features; this second picture may then be examined according to precisely defined operations, in a way not subject to the bias of language and experience.[6] The third scheme in the diagram represents a third process, based on the use of such a picture. The vague and unsatisfactory picture of the context's demands, C2, which first develops in the designer's mind, is followed by this mathematical picture, C3 Similarly, but in reverse, the design F2 is preceded by an orderly complex of diagrams F3. The derivation of these diagrams F3 from C3, though still intuitive, may be clearly understood. The form is actually shaped now by a process at the third level, remote from C2 or F2. It is out in the open, and therefore under control.

This third picture, C3, is built out of mathematical entities called "sets." A set, just as its name suggests, is any collection of things whatever, without regard to common properties, and has no internal structure until it is given one.[7] A collection of riddles in a book forms a set, a lemon and an orange and an apple form a set of three fruits, a collection of relationships like fatherhood, motherhood, brotherhood, sisterhood, forms a set (in this case a set of four elements). The elements of a set can be as abstract or as concrete as you like. It must only be possible to identify them uniquely, and to distinguish them from one another.[8]

The principal ideas of set theory are these:

1. An element x of a set S, is said to belong to that set. This is written $x \in S$. A set is uniquely defined by identifying its elements.
2. One set S_1 is said to be a subset of another set S_2, if and only if every element of S_1 belongs to S_2. This

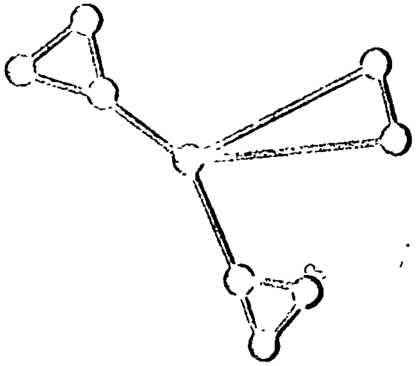
is written $S_1 \subseteq S_2$. If S_2 also contains elements which are not elements of S_1, so that S_2 is "larger" than S_1, then S_1 is called a proper subset of S_2, and we write $S_1 \subset S_2$.
3. The union of two sets S_1 and S_2 is the set of those elements which belong to either S_1 or S_2 (or both, in the case where S_1 and S_2 have elements in common). We write it as $S_1 \cup S_2$.
4. The intersection of two sets S_1 and S_2 is the set of those elements which belong to both S_1 and S_2. We write it $S_1 \cap S_2$. If S_1 and S_2 have no elements in common, this intersection is empty, and we call the sets disjoint.

Let us be specific about the use of set theory to picture design problems. We already know, from Chapter 2, what the designer's conception of a problem looks like. The problem presents itself as a task of avoiding a number of specific potential misfits between the form and some given context. Let us suppose that there are m such misfit variables: $x_1 \cdots x_m$. These misfit variables form a set. We call the set of these m misfits M, so that we may write $x_i \in M$ (for all i, $i = 1 \cdots m$).[9]

The great power and beauty of the set, as an analytical tool for design problems, is that its elements can be as various as they need be, and do not have to be restricted only to requirements which can be expressed in quantifiable form. Thus in the design of a house, the set M may contain the need for individual solitude, the need for rapid construction, the need for family comfort, the need for easy maintenance, as well as such easily quantifiable requirements as the need for low capital cost and efficiency of operation. Indeed, M may contain any requirement at all.

These requirements are the individual conditions which must be met at the form context boundary, in order to prevent misfit. The field structure of this form-context boundary, in so far as the designer is aware of it, is also not hard to describe. He knows that some of the misfits interfere with one another, as he tries to solve them, or conflict; that others have common physical implications, or concur; and that still others do not interact at all. It is the presence and absence of these interactions which give the set M the system character already referred to in Chapters 3, 4, and 5.[10] We represent the interactions by associating with M a second set L, of non-directed, signed, one-dimensional elements called links, where each link joins two elements of M, and contains no other elements of M. As we shall see in Chapter 8, the links bear a negative sign if they indicate conflict, and a positive sign if they indicate concurrence, and may also be weighted to indicate strength of interaction.

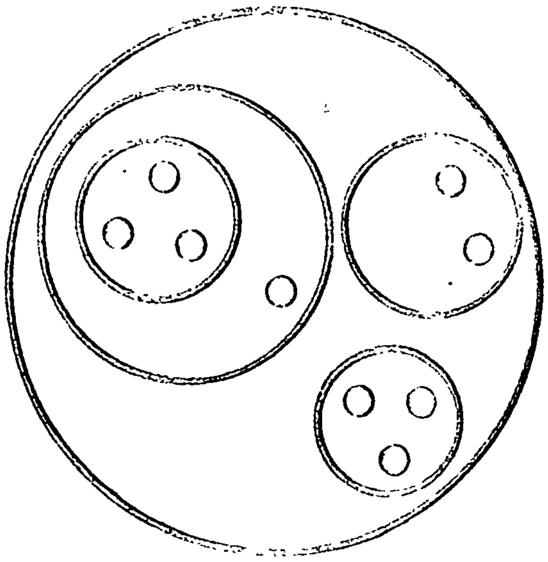
The two sets M and L together define a structure known as a linear graph or topological 1-complex, which we shall refer to as $G(M,L)$, or simply G for short.[11] A typical graph is shown below. Such a graph serves as a picture of a designer's view of



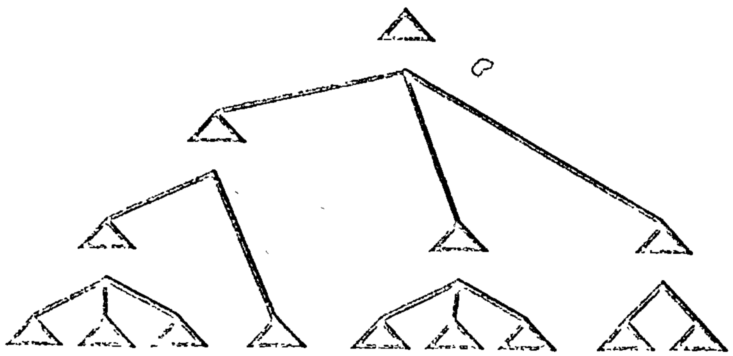
some specific problem. It is a fairly good picture, in the case that its constituents, the sets M and L, are available to him introspectively without too much trouble; also because it keeps our attention, neatly and abstractly, on the fact that the set of misfits has a structure, or, as we called it in Chapter 2, a field.[12]

We must now explore the structure of this field. The most important and most obvious structural characteristic of any complex entity is its articulation — that is, the relative density or grouping and clustering of its component elements. We will be able to make this precise by means of the concept of a decomposition.

Informally, a decomposition of a set M into its subsidiary or subsystem sets is a hierarchical nesting of sets within sets, as is shown in the first of the two diagrams that follow. A more



usual diagram, which brings out the treelike character of the decomposition, is shown below. It refers to precisely the same structure as the other. Each element of the decomposition is a subset of those sets above it in the hierarchy.



Formally I define a decomposition of a set of misfits M as a tree (or partly ordered set) of sets in which a relation of immediate subordination is defined as follows, and in which the following further conditions hold:[13]

A set S_1 is immediately subordinate to another set S_2 if and only if S_2 properly includes S_1 ($S_1 \subset S_2$), and the tree contains no further set S_3 such that $S_1 \subset S_3 \subset S_2$. Further, the tree must satisfy the following four conditions:

1. If S_i and S_j are two immediate subordinates of a set S, then $S_i \cap S_j = 0$.
2. Every set which has immediate subordinate sets is the union of all these sets.
3. There is just one set which is the immediate subordinate of no other set. This is the set M.
4. There are just m sets which have no immediate subordinates. These are the one-element sets, each of which contains one element of M.

As it stands, such a decomposition deals only with the set M. L, the set of links, plays no part in it. But it is easy to see that the existence of these links makes some of the possible decompositions very much more sensible than others. Any graph of the type $G(M,L)$ tends to pull the elements of M together in natural clusters. Our task in the next chapters is to make this precise, and to decide which decomposition of M makes the most sense, once we have a given set L associated with it. Each subset of the set M which appears in the tree will then define a subproblem of the problem M. Each subproblem will have its own integrity, and be independent of the other subproblems, so that it can be solved independently.

It is very possible, and even likely, that the way the designer initially sees the problem already hinges on a conceptual hierarchy not too much unlike a decomposition in general outline.[14] In trying to show that the links of L favor a particular decomposition, I shall really be trying to show that for every problem there is one decomposition which is especially proper to it, and that this is usually different from the one in the designer's head. For this reason we shall refer to this special decomposition as the *program* for the problem represented by $G(M,L)$. We call it a program because it provides directions or instructions to the designer, as to which subsets of M are its significant "pieces," and so which major aspects of the problem he should apply himself to. This program is a reorganization of the way the designer thinks about the problem.[15]

7 / THE REALIZATION OF THE PROGRAM

Finding the right design program for a given problem is the first phase of the design process. It is, if we like, the analytical phase of the process. This first phase of the process must of course be followed by the synthetic phase, in which a form is derived from the program. We shall call this synthetic phase *the realization of the program.*[1] Although these notes are given principally to the analytical phase of the process, and to the invention of programs which can make the synthesis of form a reasonable task, we must now spend a little time thinking about the way this synthesis or realization will work. Until we do so, we cannot know how to develop the details of the program.

The starting point of analysis is the requirement. The end product of analysis is a program, which is a tree of sets of requirements. The starting point of synthesis is the diagram. The end product of synthesis is the realization of the problem, which is a tree of diagrams. The program is made by decomposing a set of requirements into successively smaller subsets. The realization is made by making small diagrams and putting them together as the program directs, to get more and more complex diagrams. To achieve this we must learn to match each set of requirements in the program with a corresponding diagram.

The invention of diagrams is familiar to every designer. Any pattern which, by being abstracted from a real situation, conveys the physical influence of certain demands or forces is a diagram.

The famous stroboscopic photograph of the splash of a milk drop is, for certain purposes, a diagram of the way the forces go at the moment of impact. If you want to study these forces, this photograph, by abstracting their *immediate* physical consequences from the confusion of what you usually see when a milk drop falls, tells you a great deal about them.[2]

Le Corbusier's *ville radieuse* is a diagram, which expresses the physical consequences of two very simple basic requirements: that people should be housed at high overall density, and that they should yet all have equal and maximum access to sunlight and air.[3]

The sphere is a diagram. It expresses, among other things, the physical implications of the need to enclose as large a volume as possible within as small a surface as possible. It also expresses the implication of the requirement that a number of things be equidistant from a single point.[4]

The texture of bathers on a crowded bathing beach is a diagram. The evenness of the texture tells you that there are forces tending to place family groups as far as possible (and hence at equal distances) from one another, instead of allowing them to place themselves randomly.

An arrow is a diagram, of course, which conveys direction. Many flow problems contain requirements which can be summarized by means of arrows.[5] Very occasionally the form called for turns out to be physically arrow-shaped itself; like the case where the aerodynamic needs of a fast aeroplane are embodied in a swept-wing design.

Kekulé's representation of the benzene molecule (as atoms, with linear bonds between them) is again a diagram. Given the valency forces represented by the bonds, the diagram expresses the physical arrangement of the atoms, relative to one another, which is thought to result from the interaction of these valencies.[6]

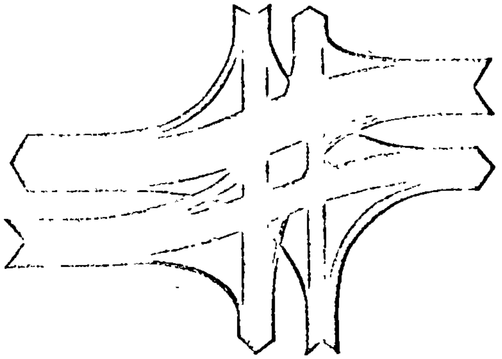
Van Doesburg's "de Stijl" drawings, though made for other reasons, could be interpreted as diagrams which present the rectilinear consequences of the need for machine tools and rapid prefabricated assembly.[7]

The engineer's preliminary sketch for a bridge structure is a diagram. After making the initial calculations, the engineer draws some pencil lines to show himself roughly how the bridge's major members might go under the influence of gravity, the given required span, the maximum tensile strength of available steel, and so on.[8]

We notice that these diagrams may have either or both of two distinct qualities, not always equally emphasized. On the one hand they may summarize aspects of a physical structure, by presenting one of the constituent patterns of its organization (as the photograph of the milk splash does, or the drawings for the *ville radieuse*). Although we can often infer a great deal about the demands responsible for the particular pattern such a diagram exhibits, it remains principally a description of formal characteristics. We shall call such a diagram a form diagram. On the other hand, the diagram may be intended to summarize a set of functional properties or constraints, like the arrow, or the population density map. This kind of diagram is principally a notation for the problem, rather than for the form. We shall call such a diagram a requirement diagram.

Let us consider extreme examples of a requirement diagram and a form diagram for a simple object. The mathematical statement $F = kv^2$ expresses the fact that under certain conditions the energy lost by a moving object because of friction depends on the square of its velocity. In the design of a racing car, it is obviously important to reduce this effect as far as possible; and in this sense the mathematical statement is a requirement diagram. At the other extreme, a watercolor perspective view of a racing car is also a diagram. It summarizes certain physical aspects of the car's organization, and is therefore a legitimate form diagram. Yet clearly neither the equation nor the water color is very useful as such, in the search for form. To be useful, the equation needs to be interpreted, so that one can understand its physical consequences. Similarly the drawing needs to be drawn in such a way that the functional consequences of the car's shape are clearly comprehensible. Let us put this another way. A requirement diagram becomes useful only if it contains physical implications, that is, if it has the elements of a form diagram in it. A form diagram becomes useful only if its functional consequences are foreseeable, that is, if it has the elements of a requirement diagram in it. A diagram which expresses requirements alone or form alone is no help in effecting the translation of requirements into form, and will not play any constructive part in the search for form. We shall call a diagram constructive if and only if it is both at once — if and only if it is a requirement diagram and a form diagram at the same time. Let us consider an example.

Suppose that two streets of an existing town center are to be widened at and around their point of intersection, to lessen congestion. Suppose further that the only requirement is that today's traffic can flow without congestion. The requirement diagram, therefore, consists basically of information about how much traffic flows in various directions at different times of day. It is possible to present this information in a nonconstructive diagram by simply tabulating the flow numerically for each of the twelve possible paths, for different times of day. It is also possible, however, to present this same information in the condensed graphic form shown below.



Here we have a street map with arrows of various widths on it, representing the number of vehicles per hour flowing in various directions at peak hours. In this form the diagram indicates directly what form the new intersection must take. Clearly a thick arrow requires a wide street, so that the overall pattern called for emerges directly from the diagram.[9] It is both a requirement diagram and a form diagram. This diagram is a constructive one.

The constructive diagram is the bridge between requirements and form. But its great beauty is that it goes deeper still. The same duality between requirement and form which the constructive diagram is able to express and unify also

appears at a second level: the duality is itself characteristic of our knowledge of form.

Every form can be described in two ways: from the point of view of what it is, and from the point of view of what it does. What it is is sometimes called the formal description. What it does, when it is put in contact with other things, is sometimes called the functional description.

Here are some formal descriptions. A raincoat is three feet long, made of polythene $\frac{1}{2}$ mm thick, its sleeves cut in such and such a way, and so on. A salt crystal is a cubical arrangement of alternating sodium and chloride ions. A human body contains a heart, of such and such a size, in this position in the chest, a pair of kidneys rather lower and further back; and so on again. These descriptions specify size, position, pattern, material.

The corresponding functional descriptions tell you what happens when these objects are put in various contexts in the world. The raincoat is impervious to rain, and melts when heated. The salt crystal is transparent, conducts electricity slightly, dissolves in water but not in oil, shatters when hit hard with a hammer, and so on. The heart beats faster at high altitudes, the kidneys work when the body is fed.

In many of these cases we should find it hard to relate the two descriptions to one another, because we do not understand the objects thoroughly enough, and do not know, say, how the arrangement of atoms in a crystal relates to the solubility of the crystal in different solutes. However, for some very simple objects, there is virtually no rift between formal and functional descriptions. Take a soap bubble for instance, or a soap film on a wire frame. The behavior of soap films is so thoroughly understood that we know the functional properties of any given physical arrangement, and we know what shapes and sizes of bubbles different external conditions lead to.[10] In this case, the formal descriptions and the functional descriptions are just different ways of saying the same things; we can say, if we like, that we have a unified description of a soap bubble. This unified description is the abstract equivalent of a constructive diagram.

It is the aim of science to give such a unified description for every object and phenomenon we know. The task of chemistry (and it has been remarkably successful in this) is to relate functional and formal descriptions of chemical compounds to one another, so that we can go backwards and forwards between the two, without loss in understanding. The task of physiology has been to relate the functional behavior of the body to the organs we observe in anatomy. Again, it has been reasonably successful.

The solution of a design problem is really only another effort to find a unified description. The search for realization through constructive diagrams is an effort to understand the required form so fully that there is no longer a rift between its functional specification and the shape it takes.[11]

In other words, a constructive diagram, if it is a good one, actually contributes to our understanding of the functional specification which calls it into being.

We have already seen, in Chapter 2, that the designer never really understands the context fully. He may know, piecemeal, what the context demands of the form. But he does not see the context as a single pattern — a unitary field of forces. If he is a good designer the form he invents will penetrate the problem so deeply that it not only solves it but illuminates it.

A well-designed house not only fits its context well but also illuminates the problem of just what the context is, and thereby clarifies the life which it accommodates. Thus Le Corbusier's invention of new house forms in the 1920's really represented part of the modern attempt to understand the twentieth century's new way of life.[12]

The airfoil wing section which allows airplanes to fly was invented at a time when it had just been "proved" that no machine heavier than air could fly. Its aerodynamic properties were not understood until some time after it had been in use. Indeed the invention and use of the airfoil made a substantial contribution to the development of aerodynamic theory, rather than vice versa.[13]

At the time of its invention the geodesic dome could not be calculated on the basis of the structural calculations then in use. Its invention not only solved a specific problem, but drew attention to a different way of thinking about load-bearing structures.[14]

In all these cases, the invention is based on a hunch which actually makes it easier to understand the problem. Like such a hunch, a constructive diagram will often precede the precise knowledge which could prescribe its shape on rational grounds.

It is therefore quite reasonable to think of the realization as a way of probing the context's nature, beyond the program but parallel to it. This is borne out, perhaps, by the recent tendency among designers to think of their designs as hypotheses.[15] Each constructive diagram is a tentative assumption about the nature of the context. Like a hypothesis, it relates an unclear set of forces to one another conceptually; like a hypothesis, it is usually improved by clarity and functional properties of any given physical arrangement, and we know what shapes and sizes of bubbles different external conditions lead to.[10] In this case, the formal descriptions and the functional descriptions are just different ways of saying the same things; we can say, if we like, that we have a unified description of a soap bubble. This unified description is the abstract equivalent of a constructive diagram.

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We have already seen, in Chapter 2, that the designer never really understands the context fully. He may know, piecemeal, what the context demands of the form. But he does not see the context as a single pattern — a unitary field of forces. If he is a good designer the form he invents will penetrate the problem so deeply that it not only solves it but illuminates it.

A well-designed house not only fits its context well but also illuminates the problem of just what the context is, and thereby clarifies the life which it accommodates. Thus Le Corbusier's invention of new house forms in the 1920's really represented part of the modern attempt to understand the twentieth century's new way of life.[12]

The airfoil wing section which allows airplanes to fly was invented at a time when it had just been "proved" that no machine heavier than air could fly. Its aerodynamic properties were not understood until some time after it had been in use. Indeed the invention and use of the airfoil made a substantial contribution to the development of aerodynamic theory, rather than vice versa.[13]

At the time of its invention the geodesic dome could not be calculated on the basis of the structural calculations then in use. Its invention not only solved a specific problem, but drew attention to a different way of thinking about load-bearing structures.[14]

In all these cases, the invention is based on a hunch which actually makes it easier to understand the problem. Like such a hunch, a constructive diagram will often precede the precise knowledge which could prescribe its shape on rational grounds.

It is therefore quite reasonable to think of the realization as a way of probing the context's nature, beyond the program but parallel to it. This is borne out, perhaps, by the recent tendency among designers to think of their designs as hypotheses.[15] Each constructive diagram is a tentative assumption about the nature of the context. Like a hypothesis, it relates an unclear set of forces to one another conceptually; like a hypothesis, it is usually improved by clarity and economy of notation.[16] Like a hypothesis, it cannot be obtained by deductive methods, but only by abstraction and invention. Like a hypothesis, it is rejected when a discrepancy turns up and shows that it fails to account for some new force in the context.

The constructive diagram can describe the context, and it can describe the form. It offers us a way of probing the context, and a way of searching for form. Because it manages to do both simultaneously, it offers us a bridge between requirements and form, and therefore is a most important tool in the process of design.

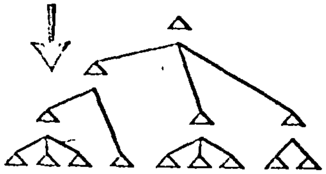
In all design tasks the designer has to translate sets of requirements into diagrams which capture their physical implications. In a literal sense these diagrams are no more than stages on the way to the specification of a form, like the circulation diagram of a building, or the expected population density map for some region under development. They specify only gross pattern aspects of the form. But the path from these diagrams to the final design is a matter of local detail. The form's basic organization is born precisely in the constructive diagrams which precede its design.

What we must now see is that the constructive diagram is not only useful in probing the more obvious, known aspects of a problem like circulation, but that it can also be used to create the newly discovered implications of a new problem. We have seen that the *extension* of any problem may be captured by a set of requirements; and that by the same token any new set of requirements may be regarded as the definition of a new problem. Going one step further, the *intension* (or physical meaning) of a known problem may be captured by a diagram; and by the same token the intension of any new, hitherto unconnected, set of requirements may be captured by a new diagram.[17]

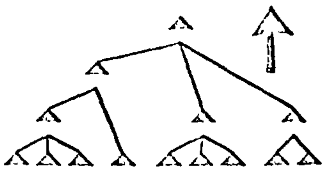
The problem is defined by a set of requirements called M. The solution to this problem will be a form which successfully satisfies all of these requirements. This form could be developed, in all its important details, as a single constructive diagram for the set M, if it were not for the complexity of M's internal interactions (represented by L), which makes it impossible to find such a diagram directly. Can we find it indirectly? Are there some simpler diagrams which the designer *can* construct, and which will contribute substantially to his ability to find a diagram for M? There are; and the program tells us how to find them.

The program is a hierarchy of the most significant subsets of M. Each subset is a subproblem with its own integrity. In the program the smallest sets fall together in larger sets; and these in turn again in larger sets. Each subset can be translated into a constructive diagram. And each of these subsets of M, because it contains fewer requirements than M itself, and less interaction between them, is simpler to diagram than M. It is therefore natural to begin by constructing diagrams for the smallest sets prescribed by the program. If we build up compound diagrams from these simplest diagrams according to the program's structure, and build up further compound diagrams from these in turn, we get a tree of diagrams. This tree of diagrams contains just one diagram for each set of requirements in the program's tree. We call it the realization of the program.

It is easy to bring out the contrast between the analytical nature of the program and the synthetic nature of its realiza-



Program, consisting of sets



Realization, consisting of diagrams

tion. As we see on the left, the tree of sets is obtained by successive division and partition. The tree of diagrams, on the right, is made by successive composition and fusion. At its apex is the last diagram, which captures the full implications of the whole problem, and is therefore the complete diagram for the form required. Examples of these two trees are given in Appendix 1.

8 / DEFINITIONS

We have seen roughly now how we shall try to represent a design problem by means of a graph, $G(M,L)$; that we shall then decompose the set M to give us a program; and how this program will be used as a basis for the construction of diagrams from which we can develop a form. We now come to the precise details of the analysis that defines the program. We begin, in this chapter, by establishing the exact character of the sets M and L which together provide us with the graph $G(M,L)$.

The problem presents itself, originally, when the ensemble is given, and when the proposed boundary between context and form, within that ensemble, is chosen. At this stage the problem is only defined within rather broad limits. Typical examples are these. We are to design a highway system for New York City; a kettle for use in the technical and cultural environment provided by metropolitan U.S.A. of 1965; a new town, for 30,000 people, forty miles from London. The context, in these cases, is fixed, and will remain constant for the duration of the problem; it may therefore be described in as much detail as possible. On the other hand, the nature of the required form is uncertain. It may be given a name, perhaps, like "kettle" or "town," to make the problem specific; but one of the designer's first tasks will be to strip the problem of the preconceptions which such names introduce.

Now, as we know already, the set M consists of all those possible kinds of misfit which might occur between the form and the context; in the case of the kettle-metropolitan U.S.A. ensemble, this set includes specific economic limitations, technical requirements of production, functional performance standards, matters of safety and appearance, and so on.[1] To be exact, each element of M is a variable which can be in one of two states, fit and misfit.[2] It is important to remember that the state of this variable depends on the entire ensemble. We cannot decide whether a misfit has occurred either by looking at the form alone, or by looking at the context alone. Misfit is a condition of the ensemble as a whole, which comes from the unsatisfactory interaction of the form and context.

Take capital cost. The variable's two states are "too expensive," which represents misfit, and "OK," which represents fit. If a kettle is too expensive, this describes a property of the kettle plus its context — that is, of the ensemble. Out of context, the kettle's price either exceeds or does not exceed various figures we can name: nothing more. Only its relation to the rest of the ensemble makes it "too expensive" or "all right." In other words, it depends on how much we can afford. Again, take the kettle's capacity. If we look at the kettle by itself, all we can say is that it holds such and such a quantity of water. We cannot say whether this is enough, until we see what the context demands. Again, the fact that the kettle does not hold enough water, or that it does, is a property of the form plus context taken as a whole. This fact, that the variable describes the ensemble as a whole, and never the form alone, leads to the following important principle. In principle, to decide whether or not a form meets a given requirement, we must construct it, put it in contact with the context in question, and test the ensemble so formed to see whether misfit occurs in it or not. You can only tell whether a kettle is comfortable enough to hold by picking it up. In principle, you can only decide whether a road is wide enough to drive down by constructing it, and trying to drive a car down it under the conditions it is supposed to meet.

Of course we do not stick to this principle in practice; it would be impossibly inconvenient if we had to. If we know the maximum width of cars to be used on the highway, and also know that for comfortable driving and adequate room for braking at a certain speed you need an extra 2′6″ on either side, we can tell in advance whether or not a given roadway is going to cause this kind of misfit or not. We can do so because the measurable character of the property "width" allows us to establish a connection between the width of the roadway and the likelihood of malfunction in the ensemble. What we do in such a case, to simplify the design task, is to establish a performance standard — in this case specifying that all roadways must have a minimum lane width of 11′0″ perhaps, because large cars are 6′ wide. We can then say, with a reasonable amount of confidence, that every road which meets this standard will not cause this misfit in the ensemble.

We can set up such a performance standard for every misfit variable that exhibits continuous variation along a well-defined scale. Other typical examples are acoustic separation of rooms (noise reduction can be expressed in decibels), illumination for comfortable reading (expressed in lumens per sq. ft.), load-bearing capacity required to prevent danger of structural failure (safety factor times maximum expected load), reasonable maintenance costs (expressed in dollars per year). Once a scale like this has been found for a requirement, it is then almost always possible to find a connection between this scale and some intrinsic property of the form;[3] thus, given a house design on the drawing board, it is possible to calculate probable maintenance costs, the noise reduction between rooms, and so on; it is then, of course, no longer necessary to find out by trial and error whether the form fails to fit its context in these respects. A performance standard determined by the context can be decided for each of them in advance, and used as a criterion of fit. For this reason there is a growing tendency to look for suitable scales, and to set up performance standards, for as many requirements as possible.[4]

However, the existence of a performance standard, and the association of a numerical scale with a misfit variable, does not mean that the misfit is any more keenly felt in the ensemble when it occurs. There are of course many, many misfits for which we do not have such a scale. Some typical examples are "boredom in an exhibition," "comfort for a kettle handle," "security for a fastener or a lock," "human warmth in a living room," "lack of variety in a park." No one has yet invented a scale for unhappiness or discomfort or uneasiness, and it is therefore not possible to set up performance standards for them. Yet these misfits are among the most critical which occur in design problems.

The importance of these nonquantifiable variables is sometimes lost in the effort to be "scientific." A variable which exhibits continuous variation is easier to manipulate mathematically, and therefore seems more suitable for a scientific treatment. But although it is certainly true that the use of performance standards makes it less necessary for a designer to rely on personal experience, it also happens that the kind of mathematical optimization which quantifiable variables make possible is largely irrelevant to the design problem.

A design problem is not an optimization problem.[5] In other words, it is not a problem of meeting any one requirement or any function of a number of requirements in the *best possible* way (though we may sometimes speak loosely as though it were, and may actually try to optimize one or two things like cost or construction time). For most requirements it is important only to satisfy them at a level which suffices to prevent misfit between the form and the context, and to do this in the least arbitrary manner possible.[6] This is a strictly binary situation. The task is to bring each binary variable to the value 0 (for continuous variables the value 0 corresponds to the whole range of values on the "good" side of the required performance standard). It is therefore only important that each variable be specific enough and clearly enough defined, so that any actual design can be classified unambiguously as a fit or misfit.

For quantifiable variables this is easy. An obvious example, in the case of the kettle, is the need for adequate capacity. Since the capacity of a kettle can be described quantitatively, we can therefore very easily set up a standard capacity which we require of satisfactory kettles, and call smaller capacity a misfit for kettles. Then we say that this variable takes the value 0 for kettles with a capacity greater than or equal to the critical capacity, and the value 1 for kettles with smaller capacity. The natural scale of capacity measurement provides an objective basis for dividing kettles into those which fit the context in this respect, and those which don't.

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For nonquantifiable variables, it is not quite so easy. Take the property "comfortable to hold" for kettles. There is no objectively measurable property that is known to correlate well enough with comfort to serve as a scale of "comfortableness." However, such a misfit variable can still be well enough defined. We can set up communicable limits which a group of experts can understand well enough to agree about classifying designs. We can certainly explain what we mean by comfort clearly enough, in commonsense language, for a group of people to learn to agree about which kettles are comfortable to hold, and which are not. This makes comfortableness an acceptable variable, for the purpose of the present analysis.

We shall treat a property of the ensemble (quantifiable or not), as an acceptable misfit variable, provided we can associate with it an unambiguous way of dividing all possible forms into two classes: those for which we agree that they fit or meet the requirement, which we describe by saying that the variable takes the value 0, and those for which we do not agree, which therefore fail to meet the requirement, and for which the variable is assigned the value 1.

This brings us to three questions, which may seem hard to answer.

1. How can we get an exhaustive set of variables M for a given problem; in other words, how can we be sure we haven't left out some important issue?
2. How do we know that all the variables we include in the list M are relevant to the problem?
3. For any specific variable, how do we decide at what point misfit occurs; or if it is a continuous variable, how do we know what value to set as a performance standard? In other words, how do we recognize the condition so far described as misfit?

These questions have already been answered, substantially, in Chapter 2. Let us remind ourselves of the fundamental principle. *Any state of affairs in the ensemble which derives from the interaction between form and context, and causes stress in the ensemble, is a misfit.*

This concept of stress or misfit is a primitive one. We shall proceed without defining it. We may find precedents for this in the practice of common law, psychiatry, medicine, engineering, anthropology, where it also serves as a primitive undefined concept.[7] In all these cases, stress is said to occur wherever it can be shown, in a common-sense way, that some state of affairs is somehow detrimental to the unity and well-being of the whole ensemble. In design too, though it may seem hard to define the concept of stress in theory, it is easy in practice. In architecture, for example, when the context is defined by a client, this client will tell you in no uncertain terms what he won't put up with. Again, it is obvious that a kettle which is uncomfortable to hold causes stress, since the context demands that it should be comfortable to hold. The fact that the kettle is for use by human hands makes this no more than common sense. At the opposite extreme, if somebody suggests that the ensemble is stressed if the kettle will not reflect ultraviolet radiation, common sense tells us to reject this — unless some special reason can be given, which shows what damage the absorption of ultraviolet does to the ensemble.

This principle that stress or misfit is a primitive concept has the following consequences. First of all, it is clearly not possible to list all the types of stress which might occur in an ensemble exhaustively, and therefore impossible to hope that M could provide an exhaustive description of a problem. A moment's thought will convince us that we are never capable of stating a design problem except in terms of the errors we have observed in past solutions to past problems. Even if we try to design something for an entirely new purpose that has never been conceived before, the best we can do in stating the problem is to anticipate how it might possibly go wrong by scanning mentally all the ways in which other things have gone wrong in the past.

The best we can do therefore is to include in M all those kinds of stress which we can imagine. The set M can never be properly called complete. The process of design, even when it has become selfconscious, remains a process of error-reduction, and the set M remains a temporary catalogue of those errors which seem to need correction.

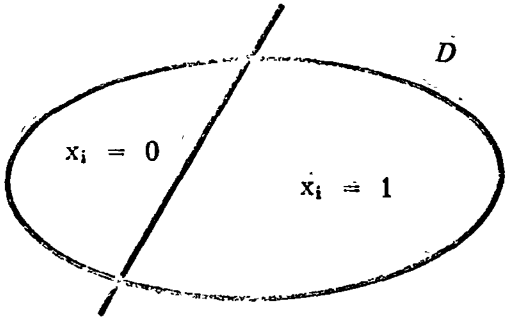
The fact that the design process must be viewed as an error-correcting process has a further consequence. The errors that seem most critical to one person will not be the same as those which seem most critical to another. Any list of errors or misfits, which are to be removed, therefore necessarily has something of a personal flavor.

For a problem like an urban dwelling, if we ask different designers to state the problem, we may find it hard even to get agreement about what the relevant issues are. Probably each designer has his private set of hunches about "where the issue really lies." The designer is free to look at a problem in any way he chooses; all we can hope to do is to put a fruitful structure on his view of it. It is for this reason that M cannot be thought of as objectively complete, and has been presented, instead, in Chapter 6, as a picture of a designer's view of a problem.

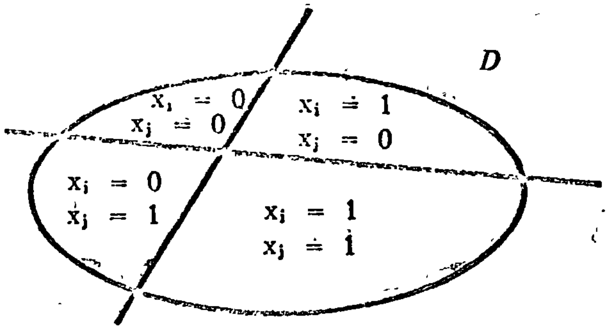
However, it should be pointed out that in spite of the natural bias which any one designer's statement of a problem is sure to carry, at the same time the use of the set M as a means of representation does have in it one great claim to neutrality. What designers disagree about is the relative importance of different requirements. In the present theory this would have to be expressed, if it were expressed at all, by assigning some sorts of weights or values to different variables. However, few designers will actually disagree about the variables themselves. While the relative importance of different requirements usually is a matter of personal opinion, the decision that a requirement either is a requirement or isn't, is less personal. The stress a misfit causes, whether slight or not, has simple tangible consequences which can be objectively determined. By leaving the designer to work out the relative importance of different requirements at his own discretion during the diagram phase of the design process, it is therefore possible for designers to agree about the contents of the set M, whether or not they agree about their relative importance, because mere inclusion of a requirement in M, as such, attaches no weight to it.

Before we say any more about the precise logical properties the misfit variables must have, we shall now define the interaction between variables. In order to do this, we must introduce a new concept: the domain of forms for which these variables are defined. Let us call it D. This domain D may be thought of roughly as the set of all those discriminable forms (good and bad) which might possibly be placed in contact with the given context to complete the ensemble. The contents of this domain cannot be specified precisely (if they could, the design problem would become a selection problem); the domain is imaginary, but serves to anchor the idea of inter-variable connections. We should think of it as the totality of possible forms within the cognitive reach of the designer. In other words, it is a shorthand way of talking about all those discriminable forms which a designer can imagine and design.[8]

Now, we know by postulate, that we can in principle decide, for each one of the forms in D, which requirements it meets, and which it fails to meet. This means that each misfit variable x_i cuts the domain D in two: into a set of those forms which fit, and a set of those which don't. Schematically we show this:



From two variables we get four sets, in which the forms take values as shown below.



If we superimpose all m variables, we get a division of the domain D into 2^m mutually exclusive classes, each labeled by a different pattern of values for $x_1 \cdots x_m$. We shall call the proportion of forms in D which do not satisfy requirement x_i the probability of the misfit x_i occurring. We write this $p(x_i = 1)$. (Naturally $0 \leqslant p(x_i = 1) \leqslant 1$.) In the same way we define the probability of avoiding the misfit x_i as $p(x_i = 0)$; and the probability of avoiding both x_i and x_j simultaneously as $p(x_i = 0, x_j = 0)$, and so forth.

If the variables $x_1 \cdots x_m$ are all pairwise independent then it is an axiom of probability theory that we may write $p(x_i = 0, x_j = 0) = p(x_i = 0) \cdot p(x_j = 0)$ for all i and j. And similarly if the variables are also three-way, four-way and n-way independent, then these independence relations hold for the conditional probabilities, and we write, for example, $p(x_i = 0, x_j = 0 \mid x_k = 1) = p(x_i = 0 \mid x_k = 1) \cdot p(x_j = 0 \mid x_k = 1)$ conditional on $x_k = 1$ and so on.[9]

Wherever the variables are not independent, the above relations break down. Essentially, then, we speak of a dependence among two variables wherever $p(x_i = 0, x_j = 0)$ is markedly unequal to $p(x_i = 0) \cdot p(x_j = 0)$, and similarly for more than two variables. Formally, we describe these dependences by means of the correlation coefficients.[10] The simplest correlation coefficient is that for two variables:[11]

$$c_{ij} = \frac{p(x_i=0,x_j=0) \cdot p(x_i=1,x_j=1) - p(x_i=0,x_j=1) \cdot p(x_i=1,x_j=0)}{[p(x_i=0)p(x_j=0)p(x_i=1)p(x_j=1)]^{\frac{1}{2}}}.$$

For any pair of variables x_i and x_j, then, we may distinguish the following three possibilities.

1. If c_{ij} is markedly less than 0, x_i and x_j conflict; like "The kettle's being too small" and "The kettle's oc-

cupying too much space." When we look for a form which avoids x_1 we weaken our chances of avoiding the other, x_2.

2. If c_{ij} is markedly greater than 0, x_i and x_j concur; like "the kettle's not being able to withstand the temperature of boiling water" and "the kettle's being liable to corrode in steamy kitchens." When we look for materials which avoid one of these difficulties, we improve our chances of avoiding the other.
3. If c_{ij} is not far from 0, x_i and x_j exhibit no noticeable interaction of either type.

In the first case we should write a negative link between the variables, in the second case we should write a positive link between them, and in the third case we should write no link at all between them. Roughly speaking, two requirements interact (and are therefore linked); if what you do about one of them in a design necessarily makes it more difficult or easier to do anything about the other.[12]

This at once suggests a simple way of estimating links, based on direct inspection of the known existing forms. Suppose we pick a sample of all the recently produced kettles we can find and examine it from the point of view of misfits x_i and x_j. Since we have defined each misfit variable in such a way that we can always decide which value it takes (0 or 1) in a given design, the proportions of kettles in our sample where x_i only has occurred ($x_i = 1, x_j = 0$), where x_j only has occurred ($x_i = 0, x_j = 1$), where both have occurred ($x_i = 1, x_j = 1$), and where neither has occurred ($x_i = 0, x_j = 0$), are easy to obtain. Provided the samples are carefully chosen, these sample proportions give us good estimates of the probability of x_i, of x_j, of both, of neither, occurring in a

randomly selected contemporary kettle. From these joint two-variable probability estimates, we could compute the correlation c_{ij}, and write a link between any pair of variables whose correlation was statistically significant. We could use the same procedure to decide on the many-variable correlations.

However, such a method, being based on a sample of existing kettles, is not what we want at all. If we think carefully, we see that empirically found correlations have very different degrees of validity. Some are almost logically necessary — like the conflict between the need for sufficient capacity in the kettle and the need for economical storage space. The first calls for large volume, the second for small volume. This conflict exists almost by definition, at least until one is thinking of ways of heating water that are very much unlike kettles.[13]

Other correlations depend on physical laws — like the conflict between the need for a material which keeps the heat in after the kettle has boiled and the need for a material which allows the kettle water to be heated cheaply. It is hard to imagine a material whose thermal conductivity is different in opposite directions; so again, although there are ways round it, the conflict exists for most of the kettles one can imagine.

But other correlations will depend only on accidents of present taste and habit. If you look at kettles in the shops today, you might notice that the cheap ones have tin handles, and you might conclude that the need for safety when you pick up a hot kettle (that is, for a handle which doesn't burn you) conflicts with the economics of production and the need to keep down capital cost. However, this conclusion, being based on a sample of presently available kettles, will change as soon as we begin to think of other materials and designs. This conflict certainly does not exist for all imaginable kettles.

Clearly we want to avoid muddling this last kind of case with the other two. If we were to accept the linkage it suggests, then together with the essential logic of the ensemble we should also be freezing in its most temporary incidentals. We are interested in those links between variables which hold for all forms we can conceive (that is, for the whole of D). Any sample based on those possible solutions which happen to have been constructed is heavily biased toward the past. To avoid the bias we should need either to examine all the members of D exhaustively or to find a theory which offers us a way of sampling D unbiasedly. Neither of these is practicable today.

However, we may overcome the bias by another means. Instead of just looking for statistical connections between variables, we may try to find causal relations between them. Blind belief based only on observed regularity is not very strong, because it is not the result of a seen causal connection. But if we can invent an explanation for inter-variable correlation in terms of some conceptual model, we shall be much better inclined to believe in the regularity, because we shall then know which kinds of extraneous circumstances are likely to upset the regularity and which are not. We call a correlation "causal" in this second case, when we have some kind of understanding or model whose rules account for it.

For example, the molecular and crystalline structure of materials gives us good reason to believe that the thermal conductivity of a material is the same in any two opposite directions, and hence that the need to heat a kettle quickly conflicts with the need to keep the water hot once it has

boiled. In this case, because we "understand" the connection between the two variables, we call it causal, and give it much greater weight — because we are convinced that it holds for almost all conceivable possibilities.

The search for causal relations of this sort cannot be mechanically experimental or statistical; it requires interpretation: to practice it we must adopt the same kind of common sense that we have to make use of all the time in the inductive part of science. The data of scientific method never go further than to display regularities. We put structure into them only by inference and interpretation.[14] In just the same way, the structural facts about a system of variables in an ensemble will come only from the thoughtful interpretation of observations.

We shall say that two variables interact if and only if the designer can find some reason (or conceptual model) which makes sense to him and tells him why they should do so.[15]

Again, as with the definition of the variables, this introduces a personal bias, and reminds us that L, like M, is a picture of the way the designer sees the problem, not an objective description of the problem itself. If the designer sees a conflict between the need to have sufficient capacity in a kettle and the need to conserve storage space, he does so because he has certain preconceptions in mind about the kinds of kettle which are possible. It is true that there are conceivable devices, not yet invented, for boiling water as it comes out of the faucet, and that these might take very little storage space. But until the designer understands this possibility, there is no point in telling him that the conflict is spurious; as far as he is concerned, there really is a conflict, which needs to be resolved, and therefore needs to be included in L and taken into account in the analysis of M. It is only after first including this link in L, and in the very act of asking himself whether two variables really do interact, and why they do, that the designer sees the possibility of avoiding the conflict and so sees further into the problem.

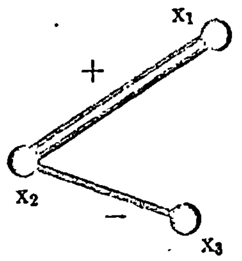
The reader may well ask how such a process, in which both the requirements and the links between requirements are defined by the designer from things already present in his mind, can possibly have any outcome which is not also already present in the designer's mind. In other words, how can all this process really be helpful? The answer is that, because it concentrates on structure, the process is able to make a coherent and therefore new whole out of incoherent pieces.

It is true that the designer must already have some physical ideas about the problem in his mind when he starts. In order to define requirements, he must be aware of the specific physical implications of each. In order to define links between requirements, he must be aware of the many specific ways in which these physical implications are likely to conflict and to concur. But the many piecemeal implications which the designer is aware of do not themselves amount to form. He is only able to define form at that moment when these physical implications coalesce in his mind, and take on organized shape. The process I am describing, as we shall see, helps precisely here, by forcing *organization* onto the specific but hitherto unorganized details in the designer's mind.

Undoubtedly the pattern of interactions in any real-world problem will have a great variety of different strengths. In one case two variables may conflict so strongly that they virtually exclude one another and can never take the same values at the same time. In another case, there may be no more than a barely discernible tendency for them to concur. But while an explicitly statistical test would give the interactions a continuous range of values, the *ad hoc* methods of practical common sense will hardly allow us to assign them a consistently scaled continuous range — particularly in view of the fact that different consultants may have incommensurable personal scales of evaluation, and that interactions which spring from different kinds of sources can be hard to compare. In practice we shall, at best, be able to distinguish two or three strengths of interaction.

In practice, then, we shall give each pair of variables (x_i, x_j) some small integral index, ν_{ij}, equal to 0 if there is no interaction, positive if there is concurrence, negative for conflict. It will usually be convenient to keep the absolute value of ν_{ij} less than or equal to some fixed integer ν. For the sake of consistent interpretation, assume that the link index ν_{ij} indicates a correlation of $\delta\nu_{ij}$, where δ is some arbitrary constant, such that $\delta\nu \leqslant 1$. We may display the values of the ν_{ij} in matrix form. The cell in the ith row and the jth column contains the value ν_{ij}. Thus the cell in the 1st row and the 2nd column ($i = 1, j = 2$) contains ν_{12}. The matrix is symmetrical. Thus

$$\begin{array}{c|c|c|c|}
 & x_1 & x_2 & x_3 \\
\hline
x_1 & 0 & 2 & 0 \\
\hline
x_2 & 2 & 0 & -1 \\
\hline
x_3 & 0 & -1 & 0 \\
\hline
\end{array}$$



From this matrix we define the set L as a set of links associated with the variables of M, as follows.[16] For every pair of variables x_i and x_j, there are $|v_{ij}|$ distinct elements of L which join x_i to x_j. These elements bear the same sign as the index v_{ij}, negative for conflict, and positive for concurrence.[17] The sets M and L together, completely define the graph $G(M,L)$.[18]

The definitions we have given so far still leave certain practical questions about the sets M and L unanswered. Does it matter, for instance, if two variables are very close in meaning, though slightly different? How specific or how general must they be? What do we do about three-variable interaction? The answers to these questions depend on three important formal properties of the system $G(M,L)$, which we shall now explore.

First of all, if the graph $G(M,L)$ is to give us an accurate picture of the variables' behavior, it is necessary that the set L describe *all* the interaction between variables which there is. Since the elements of L are links which represent two-variable correlation, this means that the váriables must be chosen to be free from three-variable and higher-order correlations. The mathematics of Appendix 2 is also based on the assumption that the higher-order correlations vanish.[19] If this is not so, any analysis based on M and L alone is sure to give misleading results.

Second, even the two-variable correlation δv_{ij} must be small, for each pair of variables. Specifically, as far as the mathematics of Appendix 2 is concerned, we must have $l\delta \leqslant 1$, where l is the total number of links in L.[20]

Third, the analysis in Appendix 2 is also based on the assumption of a certain simple symmetry among the variables of M. It demands that $p(x_i = 0)$ should be the same for all i.[21] Again, if this is not so, the analysis will be invalid.

Let us now consider the practical implications of these three formal properties which the system $G(M,L)$ must have. We take the last one first. It demands that $p(x_i = 0)$ should be the same for all i, or that the proportion of all thinkable forms which satisfy a requirement should be about the same for each requirement. What this amounts to, in common-sense language, is that all the variables should be roughly comparable in their scope and significance.

We cannot admit "economically satisfactory" as one requirement, and "maintenance costs low enough" as another. Plainly these have different degrees of significance, because the second is part of the first, while the first is not part of the second. Every design which is economically satisfactory must *a fortiori* have acceptable maintenance costs. But the reverse is not true. There are far more possible designs which meet the second than the first, because the first is much wider in scope and significance; their probabilities of occurrence are very unequal. In this case the inequality is especially clear because the second requirement is, as it were, contained in the first. But the difference would be just as great if we replaced the first by "functionally satisfactory." This is again wider in scope and significance than "maintenance costs low enough" even though it does not contain it. If we want to use "maintenance costs low enough" as one requirement, then we must break down "functionally satisfactory" into smaller, more specific requirements, comparable to it. The first step in constructing the set M is to make all its variables approximately equal in "size" or scope.[22]

Let us take the second of the three formal properties next.

In practice, of course, the preciseness of this mathematical expression is meaningless, since we judge the correlations "by eye," and do not obtain them numerically. What it does mean, in practice, though, is that we must be satisfied that all the variables are as independent as we can get them to be. An example should make this clear: Suppose the following two variables appear on our list, for the kettle problem.

1. "The kettle must heat water fast enough."
2. "The kettle must keep water hot once it is heated."

These two are clearly not at all independent. However, there are two fairly independent issues lurking behind them, if we can only find them. One way to bring this out would be by the following rearrangement, which covers more or less the same ground as the first pair, but consists of two more independent variables.

3. "The kettle must permit one-way heat transmission only."
4. "The kettle must have low thermal capacity."

A considerable amount of energy must be spent in the preliminary stages shuffling and reshuffling the variables in this fashion, until they are as independent as they can be made.[23]

The first formal property, that the three-variable or higher-order correlations among the elements of M should be negligible, is the hardest of all to achieve. It means that the two-variable correlation for any pair of variables must be independent of the states of all other variables. Since the state of one variable is most likely to affect the correlation between other variables, if that one variable is wide in scope the best we can do in satisfying this is to make all the individual variables as specific and minute as possible.

This policy of making all the variables highly specific is important for another reason. However much we may try to steer clear of existing categories, in practice we shall always have to generate the specific variables of M through intermediate stages. The brain is not made to think of such detailed lists amorphously. Whether we like it or not, if we think of one variable which has to do with acoustics, we shall inevitably then think of others which seem, to us, to fall under the same heading or to be in the same conceptual area. It is therefore a matter of practical psychology that we cannot avoid using superordinate concepts like "economics" and "acoustics" altogether, as intermediate steps in the task of listing misfit variables. At best we may treat these conceptual intermediates as key words, as loosely conceived labels for the principal issues in the problem, which we shall then break down further into finer pieces to get our set of variables M. The closer our variables are to these abstract and general key words, the more susceptible the problem remains to the kind of distortions discussed in Chapter 5. The more specific and detailed we make the variables, the less constrained $G(M,L)$ will be by previous conceptions, and the more open to detailed and unbiased examination of its causal structure.

Let us therefore sum up the properties the elements of M must have. They must be chosen (1) to be of equal scope, (2) to be as independent of one another as is reasonably possible, and (3) to be as small in scope and hence as specific and detailed and numerous as possible.[24] An example of a set M is given in Appendix 1, together with its associated set L.

9 / SOLUTION

We now have a graph $G(M,L)$ which represents the design problem. As we have seen in Chapter 6, to solve the problem, we shall try to decompose the set M in such a way that it gives us a helpful program for design. We shall now consider what criterion to use as a basis for decomposition.

As we observed in Chapter 6, a program really gives us a series of simpler subproblems, and tells us in what order to solve them. Before we try to define a decomposition criterion we may want to question the assumption that such a decomposition can be of any use at all to a designer. The designer as a form-maker is looking for integrity (in the sense of singleness); he wishes to form a unit, to synthesize, to bring elements together. A design program's origin, on the other hand, is analytical, and its effect is to fragment the problem. The opposition between these two aims, analysis and synthesis, has sometimes led people to maintain that in design intellect and art are incompatible, and that no analytical process can help a designer form unified well-organized designs.

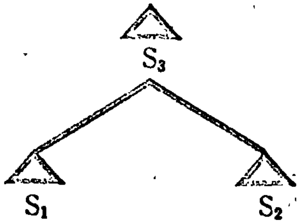
Let us look at this objection to analysis more closely. It is a common experience that attempts to solve one piece of a problem first, then others, and so on, lead to endless involutions. You no sooner solve one aspect of a thing than another is put out of joint. And when you go back to correct that one,

something else goes wrong. You go round and round in circles, unable ever to produce a form which is thoroughly right, because there is no way of integrating the pieces you have tackled independently. This is the great argument against attempts to solve design problems piecemeal. And it is argued further that, since no amount of analyzable juggling can ever solve this difficulty, the designer has to rely on a subconscious creative force to juggle the pieces more successfully. His hand and eye must be secure enough, in other words, to take him to his answer more immediately than his intelligence can. If design problems were homogeneous, this recommendation would be important. For then any analytical subdivision would, so to speak, put cracks in them, which would destroy their unity. As it happens though, in practice problems are not homogeneous. They are full of knots and crevices which exhibit a well-defined structure. An analytical process fails only if it does not take this structure into account. If we can learn to draw the gross structural components of the problem out of the graph $G(M,L)$ which represents it, the difficulty will disappear.

The question is, how are these separable structural components of a problem to be recognized? We face this kind of task every day, constantly, even when we see nothing more complicated than a pair of oranges on a table side by side. In seeing two oranges lying side by side, and not one and a half oranges lying next to half an orange, we have recognized the structural components correctly. (Correctly, of course, because while we can pick either orange up and leave the other where it is, we cannot pick up $1\frac{1}{2}$ oranges, and leave $\frac{1}{2}$ an orange lying there.) Köhler and Wertheimer drew attention to the fact that even an apparently simple cognitive act like this, in fact demands a very complex perceptual operation.[1] It is not surprising to find, in the similar but more abstract task of recognizing the proper structural components of the system M, that our native perception and intuition fail us.

The task of replacing this intuition by some precisely defined mathematical operation has been tackled in a number of ways.[2] Many of them are worth examining, if for no better reason than that they will illustrate and deepen our conception of the task. One, which perhaps comes closest to what we want, simply divides M into those subsets which are connected by as few links of L as possible, thus leaving as many of the links as possible within the subsystems.[3] However, neither this nor any other of the existing methods is exactly suited to the conditions which confront us in this case. I shall now try to show that we can develop a well-defined criterion for decomposition, simply by thinking carefully about the relation between a design program and its realization.

Let us think just what the successful realization of the program demands. Fundamentally, it demands that the sets in the program have two kinds of property, which we may illustrate by taking the typical piece of a program shown below. S_1 and S_2 are two different sets of requirements. S_3 contains all the requirements in S_1 and S_2 together.



First we must be able to find constructive diagrams for S_1 and S_2 individually. This means that the misfits which S_1 contains must cohere somehow, and suggest a physical aspect or component of the form under consideration; and the same for S_2.

Secondly, if the decomposition is to serve any useful purpose, it must not be necessary to construct the diagram for S_3 from scratch. Instead, it must be possible to derive a constructive diagram for S_3 in some simple way from the diagrams already constructed for S_1 and S_2 in isolation.

To put it simply, the first of these conditions depends on the internal structure of the sets S_1 and S_2, while the second deals with the relations between these two sets.

Let us take the two conditions in order.

What is it about the internal structure of any problem that makes it hard to solve? In nine cases out of ten, we cannot solve it, because we cannot grasp it; we cannot see what the internal structure is "driving at." The subproblems we are considering here, because they are made up of sets of requirements that have been isolated from the rest of the design problem they belong to, show this acutely. Take two misfits at random: "The kettle must be comfortable for the hand to hold," and "The kettle must be economical to heat," which we should probably consider as noninteracting. These two define a two-element subset of M for the kettle problem. It is hard to see, however, what these two elements have in common, or indeed whether this set, taken by itself, means anything.

If the set M contains m misfits, there are 2^m possible subsets of M, and so 2^m subsidiary problems. Any design problem of practical interest and complexity will probably contain at least as many as 100 variables, and will therefore have 2^{100} or roughly 10^{30} (1,000,000,000,000,000,000,000,000,000,000) different subsets of variables. Almost each one of these subsets will be hard to grasp, because, as in the example of the two-element subset just given, it will not be clear what its rather disparate member-variables "have in common."

Our natural reaction to this is to look for those very rare sets of variables with integrity in which the variables do "have something in common," so that they do make sense.

The use of verbal concepts is an efficient artificial way of finding sets which have something in common. Certain issues which appear in our analysis as subsets of M, happen to be tied together by familiar words; as a result everyone comes to be able to manipulate these sets, can understand what he is dealing with, and can therefore get to grips with the issues the set represents.

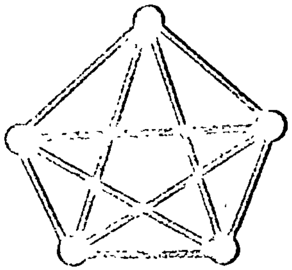
Unfortunately, the sets of misfits identified by verbal concepts do not have any special functional significance, and do not usually lend themselves particularly well to interpretation through constructive diagrams. A constructive diagram requires that the requirements it represents have some physical implications in common. From this point of view, it is easy to see that not all the possible subsets of M will be equally easy to diagram constructively. We may put this another way, perhaps, by saying that some subsets open up physical possibilities more readily than others. Some sets of misfits, in view of their interactions, seem naturally to belong together, and, taken as units, suggest physical form very strongly. Others will seem to have no special reason for being sets, and are not

especially easy to diagram, and do not really "belong" to the problem.

If we are to make anything sensible of the subsets in this program, we must now ask just which sets of points to consider as being the most "diagrammable." This depends on the pattern of interactions between the misfits. Where, after all, does the interaction among the requirements spring from? It springs from the intractable nature of the available materials and the conditions under which the form has to be made. Two misfits are seen to interact only because, in some sense at least, they deal with the same kind of physical consideration. If they dealt with utterly different aspects, there could be no basis either for conflict or for concurrence.

In building, the need for acoustic insulation conflicts with the need to build with easily transportable prefabricated materials. These two needs conflict because the first calls for massive inert walls, while the second calls for light walls. The physical feature of the world their interaction depends on is mass. Again, in a highway, the need for safety on curves conflicts with the need to keep land costs down, because the wider the curves have to be for safety's sake, the larger the area eaten up by the transition curves at interchanges. In this case the interaction between the two requirements depends on the radius of the curve.

It is such a physical center of implication, if I may call it that, which the designer finds it easy to grasp. Because it refers to a distinguishable physical property or entity, it can be expressed diagrammatically, and provides a possible nonverbal point of entry into the problem. If we can find sets of variables in which there are specially dense interactions, we may assume, in these cases, that the density of the interaction resides in a particularly strong identifiable physical aspect of the problem. These sets will be the easiest of all to grasp constructively. Thus:



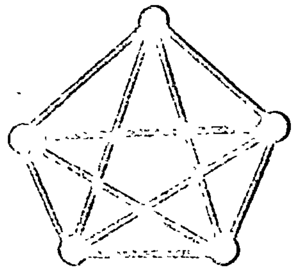
If, therefore, we break the problem apart in such a way that its clusters of variables are as richly connected, internally, as possible, we shall have clues to those physical aspects of the problem which play the most important functional part in the problem and are therefore most likely to furnish handles for the designer's comprehension. These are the sets which will be the easiest to diagram.

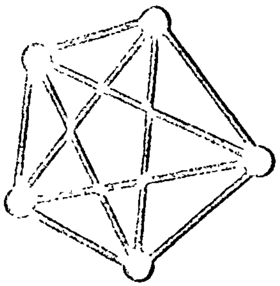
If we are to solve the problem M by working our way through the program, solving various subproblems separately, it must obviously be possible to put the resulting diagrams together somehow when we have them. This is the second condition a successful program must satisfy. But it will only be possible to fuse two diagrams under very special circumstances. Why, for instance, can we not simply make a diagram for each separate variable, so that we get m diagrams, and superimpose these m diagrams somehow? The reason is obvious. The physical characteristics demanded by one requirement conflict with the physical characteristics demanded by

another. This is, in fact, exactly what we mean by saying that two misfit variables conflict. The same is true of more complex diagrams. We have already drawn attention to the fact that a subset which contained all the economic variables and no others, for example, would be comparatively useless, because its economic implications conflict too strongly with the other implications of the problem. Naturally if the diagram for the economic requirements is not going to be compatible with that for the comfort requirements, say, there is no point in constructing the two diagrams independently.

How shall we meet this difficulty? At all events, we cannot avoid encountering the conflicts somewhere in the program. No matter in what order we consider the requirements, if we are to find a form which satisfies them all, we must at some stage resolve each one of the conflicts. But if we think about it, we see that the difficulty of resolving them is different at different stages of the process of realization. At the beginning of the process, the sets of requirements we apply ourselves to are still small enough for their implications to be carried in the mind's eye; and these implications are therefore not yet frozen in any explicit diagrammatic form; they are still flexible enough to be successfully integrated with one another in spite of conflicts. The further along in the process we are, the more our thoughts about these implications have been forced by their complexity to become concrete, whether diagrammatically or conceptually, and the more their rigidity resists further modification. As a result, the later in the process conflicting diagrams have to be integrated, the more difficult the integration is.

Naturally, then, since the conflicts have to be resolved sooner or later, we should like to meet them as early in the process of realization as we can, while our ideas are still flexible. From this point of view, the fewer links there are between the major subsets of the decomposition, the better. Ideally, we should like to find a first partition of M like this, for instance, where no links are cut by the partition, though this will not in practice usually be possible.[4]





The need for subsets we can grasp diagrammatically calls for sets of variables whose *internal* interactions are very rich. The need to resolve the conflicts between the diagrams we get from them calls for as little interaction *between* subsets as possible. Clearly these two are compatible; indeed, they can be expressed jointly as follows.

Consider just one level of the decomposition, where some set S is to be partitioned into disjoint subsets $(S_1, S_2 \cdots S_\alpha \cdots S_\mu)$. We wish to choose these S_α in such a way that we can invent a constructive diagram for S_1 whose implications will not later turn out to be hopelessly contradicted by an independently conceived diagram for one of the other S_α; and the same for S_2, S_3, etcetera. Why is this difficult to do in terms of the variables' behavior?

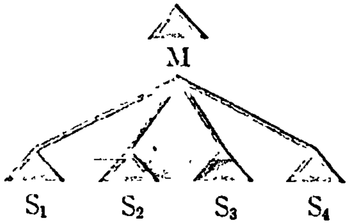
It is difficult because any variables which are linked exercise mutual constraint over one another's states. If we fix the values of the variables of S_1, the values which the variables of the other S_α can take are already constrained to some extent by the probabilistic links which bind them to this S_1. In other words, the values which the variables of S_1 take, tell us something about the values which the variables in the other S_α can take; they give us information. The sparser the links between the S_α, the less the values of the variables in S_1 can tell us about the values in S_2, etc.; the less information the links carry across the partition, the freer we are to construct a diagram for S_2 once we have fixed the solution of S_1 in our minds.

If we wish to construct a diagram for S_1 first, say, and then wish to construct a compatible diagram for S_2 independently, we want to be free to manipulate the values of the variables in S_2 without this manipulation being constrained by the fact that the variables of S_1 are now held constant in our minds, by the diagrammatic expression invented for them. To achieve this, we must choose the S_α in such a way that the variables in different subsets of the partition exercise as little informational constraint on one another as possible.

As shown in Appendix 2, the conditions specified in Chapter 8 define a unique probability distribution $p(\lambda)$ over the states λ of any set of variables S.[5] Appendix 2 then shows that, given any partition π of a set S into subsets, $\pi\{S_1 \cdots S_\mu\}$, we may establish a measure of information transfer or informational dependence among these subsets, called $R(\pi)$.[6] Since this $R(\pi)$ is defined for all possible partitions of any S, we may obtain the desired decomposition of the set M, by minimizing $R(\pi)$ for successive partitions of M and its descendants.

Thus, we first find that partition of M, $\pi(M)$, for which

$R(\pi)$ is minimum. This establishes the first level of the decomposition, thus, say:



We then apply the same method to the sets S_α: we look for that partition $\pi(S_1)$ of S_1, for which $R(\pi)$ is minimum, and similarly for $S_2 \cdots$, thus obtaining the second level of the decomposition. We continue with this procedure iteratively, until we reach a level of decomposition at which all the sets contain one variable only. (Condition 4 of Chapter 6, page 82.)

The tree of sets this decomposition gives is, within the terms of this book, a complete structural description of the design problem defined by M; and it therefore serves as a program for the synthesis of a form which solves this problem.

Let us remember the properties of the program.

1. The tree is, in its hierarchical form, the same as any other hierarchy of concepts — except that the concepts are here defined extensionally as sets of variables, rather than intensionally by meaning.
2. The particular tree arrived at by the method outlined gives an explicit description of the structure implicitly responsible for the success and stability of the unselfconscious form-making process.
3. The tree gives the strongest possible decomposition of the problem that does not interfere with the task

of synthesizing its parts in a unified way. Each subsidiary problem it defines has its own integrity, and is as independent as it can be of the rest of the problem.

4. We must remember that the hierarchy of sets which the tree defines will not always be easy to understand. Even in some of the smaller sets which contain only half a dozen variables, these variables will often seem disparate, and their juxtaposition may be startling. The relevance of each variable is only to be properly understood after careful examination of its functional relation to the other variables in the set. Since the potential coherence of such a set of variables comes from its physical implications, it can only be grasped graphically, by means of a constructive diagram that brings out these implications. Each diagram for a set S must do two things:

   As a requirement diagram:

   a. It must bring out just those features of the problem which are relevant to this set of requirements.
   b. It must include no information which is not explicitly called for by these requirements.

   As a form diagram:

   a. It must be so specific that it has all the physical characteristics called for by the requirements of S.
   b. Yet it must be so general that it contains no arbitrary characteristics, and so summarizes, abstractly, the nature of every form which might satisfy S.

   Above all, the designer must resist the temptation to summarize the contents of the tree in terms of well-known verbal concepts. He must not expect to be able

> to see for every *S* some verbal paradigm like "This one deals with the acoustic aspects of the form." If he tries to do that, he denies the whole purpose of the analysis, by allowing verbal preconceptions to interfere with the pattern which the program shows him. The effect of the design program is that each set of requirements draws his attention to just one major physical and functional issue, rather than to some verbal or preconceived issue. It thereby forces him to consolidate the physical ideas present in his mind as seedlings, and to make physical order out of them.

To finish this section I give an example of the way a set of requirements, when taken together, create a new idea about what one main feature of a physical form ought to be. Consider the design of the now familiar one-hole kettle. The single wide short spout embraces a number of requirements: all those which center round the problems of getting water in and out of the kettle, the problem of doing it safely without the lid's falling off, the problem of making manufacture as simple as possible, the problem of providing warning when the kettle boils, the need for internal maintenance. In the old kettles these requirements were met separately by three components: a spout for pouring, a hole in the top for filling and cleaning, and a top which kept the steam in and rattled when the kettle boiled. Sudden~~ly,~~ when it became possible to put noncorrosive metals on the market, and cheap, available descaler made it unnecessary to get into the kettle for descaling, it became apparent that all these requirements really had a single center of physical implication, not three. The wide spout can be used for filling and pouring, and as a whistle, and there is no top to fall open and let scalding water out over the pourer's hands. The set of requirements, once its unity is recognized, leads to a single physical component of the kettle.

The program, which represents a functional decomposition of the problem, is a way of identifying the problem's major functional aspects. But what kind of physical form, exactly, is the designer likely to realize with the help of such a program? Let us look at the form problem from the beginning.

The organization of any complex physical object is hierarchical. It is true that, if we wish, we may dismiss this observation as an hallucination caused by the way the human brain, being disposed to see in terms of articulations and hierarchies, perceives the world. On the whole, though, there are good reasons to believe in the hierarchical subdivision of the world as an objective feature of reality. Indeed, many scientists, trying to understand the physical world, find that they have first to identify its physical components, much as I have argued in these notes for isolating the abstract components of a problem. To understand the human body you need to know what to consider as its principal functional and structural divisions. You cannot understand it until you recognize the nervous system, the hormonal system, the vasomotor system, the heart, the arms, legs, trunk, head, and so on as entities.[7] You cannot understand chemistry without knowing the pieces of which molecules are made. You cannot claim to have much understanding of the universe until you recognize its galaxies as important pieces. You cannot understand the modern city until you know that although roads are physically intertwined with the distribution of services, the two remain functionally distinct.

Scientists try to identify the components of existing structure. Designers try to shape the components of new structures. The search for the right components, and the right way to build the form up from these components, is the greatest physical challenge faced by the designer. I believe that if the hierarchical program is intelligently used, it offers the key to this very basic problem — and will actually point to the major physical components of which the form should consist.

When we consider the kinds of constructive diagram which are likely to be suggested by sets of requirements, at first it seems that the nature of these diagrams is very various. Some diagrams seem to define overall pattern properties of the form, like being circular, being low rather than high, being homogeneous. Other diagrams seem to be piecelike rather than patternlike. They define pieces of which the whole form is made, like a diagram defining the street as a piece of the city, or the handle as a piece of the kettle, and so on.

Actually the distinction between patternlike and piecelike diagrams is more apparent than real. Take a simple example, a diagram which specifies a circular plan. Being circular is usually thought of as an overall property of a plan. But the plan's being circular may also be guaranteed by a surrounding wall or boundary of some sort. In other words, we can invest what is apparently a pattern property in a component which is much more of a piece: namely the boundary.

This is the general rule. Every aspect of a form, whether piecelike or patternlike, can be understood as a structure of components. Every object is a hierarchy of components, the large ones specifying the pattern of distribution of the smaller ones, the small ones themselves, though at first sight more clearly piecelike, in fact again patterns specifying the arrangement and distribution of still smaller components.

Every component has this twofold nature: it is first a unit, and second a pattern, both a pattern and a unit. Its nature as a unit makes it an entity distinct from its surroundings. Its nature as a pattern specifies the arrangement of its own component units. It is the culmination of the designer's task to make every diagram both a pattern and a unit. As a unit it will fit into the hierarchy of larger components that fall above it; as a pattern it will specify the hierarchy of smaller components which it itself is made of.

The hierarchical composition of these diagrams will then lead to a physical object whose structural hierarchy is the exact counterpart of the functional hierarchy established during the analysis of the problem; as the program clarifies the component *sources* of the form's structure, so its realization, in parallel, will actually begin to define the form's *physical* components and their hierarchical organization.[8]

EPILOGUE

My main task has been to show that there is a deep and important underlying structural correspondence between the pattern of a problem and the process of designing a physical form which answers that problem. I believe that the great architect has in the past always been aware of the patterned similarity of problem and process, and that it is only the sense of this similarity of structure that ever led him to the design of great forms.

The same pattern is implicit in the action of the unselfconscious form-producing system, and responsible for its success. But before we can ourselves turn a problem into form, because we are selfconscious, we need to make explicit maps of the problem's structure, and therefore need first to invent a conceptual framework for such maps. This is all that I have tried to do.

Since my effort may well meet with resistance, I like to see the few steps taken here reflected in a parable of an imaginary past society.

Suppose there was once a people who had no formalized arithmetic. When they wanted what we think of as arithmetical results, they got them by guessing. So if they wished to know the area of a corn patch they paced its two sides (six paces by ten paces, say), and then mulled the two numbers over. Eventually one of them came up with an answer — he would say some number, that is, which estimated the bags of corn needed to sow that patch. He might say 60, 61, 58, whatever occurred to him. (If we were in such a situation we should form what we call the product of the two numbers, 60, and determine the amount of corn needed in terms of this area.)

It is easy to see that the people of this imaginary society might not have found formal arithmetic acceptable. Their own method was usually not too far off the mark (sowing corn is such a loose test, anyway, that what we call inaccuracy would not have been noticeable) — and besides, there was something rather noble about the seers (magicians?) who performed the tasks of "calculation." Some men were better at it than others, certainly; some had the power to produce appropriate answers, some produced answers rather wider of the mark. But that didn't seem to matter. Instead the power was regarded as a great human gift, the people who possessed it were honored for their capability. And both these seers themselves and their admirers opposed the introduction of a formalized arithmetic most rigidly, did not see the possible developments, were interested only in preserving their own limited capacities for calculation.

Such resistance was not altogether foolish either. There were wise men, too, among those who opposed arithmetic. They foresaw, correctly, the materialism which it would induce. Its very first achievement, once introduced, would be to make calculation more precise and easier, and thereby to save corn. And soon number and economy and size would dominate the human being. The immediate good done by the formulation of arithmetic would be small, and not worth taking risks for on its own account.

What neither the wise men nor the seers foresaw, however, was the miraculous developments that this formulation later led to. By first understanding the shape of the technique which produced the form of the result, man found further insight. He found that it is not only the result which is important, but the process too. Not only the form of the results, but the form of the path which led to them. It was only by questioning the foundations of geometry and the processes of geometrical proof that Riemann *invented the geometry which later became the basis for Einstein's theory of relativity. Other great theories are possible today because [illegible] redefined. It was only because man gave thought to the seemingly obvious processes which underlay arithmetic that he was able to refine mathematics, and able to proceed to forms of still higher order, mathematical shapes of greater elegance and fuller understanding.*

The shapes of mathematics are abstract, of course, and the shapes of architecture concrete and human. But that difference is inessential. The crucial quality of shape, no matter of what kind, lies in its organization, and when we think of it this way we call it form. Man's feeling for mathematical form was able to develop only from his feeling for the processes of proof. I believe that our feeling for architectural form can never reach a comparable order of development, until we too have first learned a comparable feeling for the process of design.

APPENDICES

5. ANALISIS ECONOMICO PARA DETERMINAR LA MEJOR UTILIZACION DE UN TERRENO

TESIS PROFESIONAL:

Miguel Morayta Martínez.

México, 1967.

ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

ANALISIS ECONOMICO PARA DETERMINAR LA MEJOR UTILIZACION DE UN TERRENO

(5)

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Todas las restricciones importantes respecto a las utilizaciones factibles de un terreno podemos condensarlas en dos grupos: unas codificadas en reglamentos de construcción, otras derivadas directamente del inversor.

Aquí solo veremos aquellas procedentes del Reglamento de construcciones para el Distrito Federal.

De las derivadas del inversor ó cliente potencial, la mas importante sería la económica. De nada serviría, llegar a la conclusión de que para un determinado terreno, la mejor utilización sería un cierto tipo de construcción para la cual el inversor no reuniera el suficiente capital.

Las primeras disposiciones del Reglamento de Construcciones para el Distrito Federal es su alcance a "todas las obras o instalaciones públicas ó privadas que se ejecuten en terrenos de propiedad privada ó pública ó en las vías públicas, así como el uso de predios, construcciones, estructuras, instalaciones y servicios públicos".

La agencia gubernamental encargada de hacer cumplir las disposiciones del Reglamento es la Dirección General de Obras Públicas y entre las facultades de esta dependencia está el controlar el uso de los terrenos de acuerdo con el interés público y desde luego inspeccionar para conocer el uso que se haga de un predio, estructura, instalación edificio ó construcción y en consecuencia autorizar ó negar, de acuerdo con el Reglamento, la ocupación ó el uso de una construcción, estructura ó instalación.

En los artículos 4o, 5o, 6o, 7o, 9o y 10o se reglamenta la vía pública y todos los demas bienes de uso común ó destinados a un servicio público. En estos artículos se define lo que se entiende por vía pública encontrándonos la primera restricción: el uso de la vía pública para lo cual se requiera un permiso especial.

La generalidad de los casos limita los predios ó el uso de la tierra por "la superficie engendrada por la generatriz vertical que sigue el alineamiento oficial ó el lindero de la vía pública". Las vías públicas son inalienables e imprescriptibles y no solamente esto sino que existe la "presunción de vía pública" que es "todo inmueble que aparezca como vía pública en algún plano o registro oficial existente en cualquiera de las dependencias del Departamento del Distrito Federal, de la Tesorería ó en el Archivo General de la Nación"; estos, "se presumirá que es vía pública y que pertenece al Departamento del Distrito Federal, salvo prueba plena en contrario".

Nadie podrá construir en la vía pública, ni siquiera ejecutar obras que de alguna manera modifiquen las existentes sin obtener la licencia respectiva de la Dirección General de Obras Públicas.

Los artículos 19 y 20 restringen los cortes en las aceras y las ruptura de pavimentos reservándose la Dirección el ordenar bajo que condiciones se deban hacer este tipo de trabajos cuando se necesiten.

El artículo 21 da las limitaciones de voladizos y salientes o sea de cualquier elemento estructural que invada la vía pública sobresaliendo del alineamiento. Las pilastras, sardineles, marcos de puertas y ventanas, repisones, cornisas y cejas, estan restringidos por una cierta medida.

Los balcones y las hojas de las ventanas que se abren hacia afuera estan en función de su distancia a las lineas de transmisión eléctrica. Las marquesinas no se podrán usar como piso cuando se construyen sobre la vía pública. Termina este artículo restringiendo aun mas el uso de estas piezas: "las licencias que se expidan para los elementos señalados en este artículo, tendran siempre el caracter de revocable".

Todos los voladizos y salientes deberán drenarse convenientemente de tal modo que la caida del agua no sea sobre la acera.

No se puede usar la vía pública para aumentar el area util de un predio ni en forma aerea ni subterranea y el que invada la vía pública con este tipo de construcciones está obligado a retirarlas.

El capítulo IV del Reglamento define como alineamiento oficial "la trazo sobre el terreno que limita el predio respectivo con la vía pública en uso o con la futura vía pública determinada en los proyectos aprobados por los órganos o autoridades Competentes". La Dirección fija restricciones de cada predio al solicitarsele el alineamiento oficial. Para esta petición hay que precisar el uso que se pretenda dar al predio. Sin este documento no se otorga la licencia para construir.

El artículo 34 reglamenta que la Dirección "establecera las restricciones que juzgue necesarias para la construcción o para el uso de los bienes inmuebles ya sea en forma general, en determinadas zonas, en fraccionamientos, en lugares o en casos concretos y las hará constar en los permisos, licencias ó alineamientos que expida quedando obligados los propietarios o poseedores de los inmuebles a respetarlas".

El capítulo V restringe y da las especificaciones a que deba atenerse los constructores de instalaciones aereas como son los postes ó instalaciones subterraneas para los servicios públicos de teléfonos, alumbrado, semáforos, etc.

Hasta ahora, hemos visto el título I del Reglamento que establece restricciones de tipo general. El título II restringe el proyecto arquitectónico, para este efecto, la Dirección "determinará las características de los edificios y los lugares en que estos pueden autorizarse, según sus diferentes clases y usos" por lo tanto "aprobará ó rechazará los proyectos arquitectónicos de acuerdo con sus características generales y particulares."

Las construcciones que se ubiquen en zonas típicas y en calles ó plazas ó próximas a construcciones declaradas monumentos a juicio del Instituto de Antropología e Historia, deberán armonizar con el ambiente general de que formen parte.

Los materiales especificados en el proyecto deben ser de la especie y calidad necesarias al uso que se destine cada parte del mismo.

El proyecto deberá incluir las máximas seguridades contra incendio.

Todo edificio que tenga piezas habitables y que estén a una altura mayor de trece metros sobre el nivel de la acera, deberá tener por lo menos, en servicio un ascensor para personas.

En el capítulo VII se restringen las alturas de los edificios y los espacios que deben quedar sin construir.

Ningún punto del edificio puede estar a mayor altura que 1.75 veces su distancia al paramento vertical correspondiente al alineamiento opuesto de la calle. En plazas y jardines el alineamiento opuesto se localizará a cinco metros de la guarnición o en el límite interior de la acera si esta tiene mas de cinco metros de anchura. Cuando el edificio se vaya a construir en esquina de un cruce de calles de anchuras diferentes, la altura de la fachada en el alineamiento de la calle angosta, podrá ser la de la fachada en el alineamiento de la calle ancha, hasta una distancia equivalente a vez y media la anchura de la calle angosta, medida a partir de la esquina.

Todos los edificios deberán tener los espacios sin construir necesarios para lograr una buena iluminación y ventilación. Estas areas sin construir se dan en el Reglamento como mínimas. Para hoteles, oficinas y escuelas se dan en un por ciento de las areas construidas. En salas de espectáculos y centros de reunión en general se dan en función de una cierta area fija por concurrente. En los edificios industriales la Dirección

misma fija las limitaciones en cada caso específico. En aquellos edificios que se destinen a uso mixto, serán por lo menos iguales á la suma de las que se requieran para cada fin salvo que se demuestren que no existe superposición de horarios en su funcionamiento.

A partir del nivel en que se desplanten los pisos de un edificio destinado a habitación; deberán quedar libres las superficies dedicadas a patios que sirvan para dar iluminación y ventilación a las diferentes dependencias, sin que dichas superficies puedan ser cubiertas con volados, corredores, pasillos o escaleras. Se entiende por pieza habitable "los locales que se destinen a salas, despachos, comedores y dormitorios" y por no habitables aquellas "destinadas a cocinas y cuartos de baño". El destino de cada local será el que resulte de su ubicación y dimensiones y no el que se lequiera fijar arbitrariamente. El artículo 61 dá las dimensiones mínimas tanto en anchuara como en altura para poder considerar un local como pieza habitable. El reglamento en su artículo 62, solo autoriza la construcción de viviendas con un mínimo de una pieza habitable con sus servicios completos de cocina y baño.

Todas las piezas habitables en todos los pisos deberán tener iluminación y ventilación por medio de vanos que darán directamente a patios ó a la vía pública. Las superficies libres de toda obstrucción para ventilación e iluminación estan en relación de la superficie de la pieza, así, el artículo 63 da unos mínimos para estas areas de un octavo y de un venticuatravo de la superficie de la pieza para iluminación y ventilación respectivamente. El artículo 64 dá las dimensiones mínimas de los patios que sirvan para dar iluminación y ventilación a piezas habitables. Estas dimensiones mínimas estan en función de las alturas de los muros que limten estos patios. Cuando la altura de los muros limítrofes sobrepasa los 12.-- m. la dimensión mínima del patio será el tercio de la altura total de dichos muros. En este mismo artículo se dán tambien las dimensiones mínimas de los patios que sirvan para dar iluminación y ventilación a piezas no habitables. Asimismo cuando la altura de los muros limítrofes sobre pasa los 12.00 m. la dimensión mínima del patio será el quinto de la altura total de dichos muros. Ademas de la iluminación natural, se debe proveer a los edificios para habitación, de iluminación artificial que se fija en el capítulo XXI del Reglamento.

Todas las viviendas de un edificio deberán tener salida a pasillos ó corredores que conduzcan directamente a las puertas de salida ó a las escaleras. El ancho de estos pasillos así como la altura de barandales, cuando las necesiten, se especifican en el artículo 66.

Los edificios tendrán siempre escaleras que comuniquen todos los niveles, aunque tengan elevadores. Las escaleras se deberán construir con materiales incombustibles y protegerse con barandales.

El capítulo IX reglamenta los edificios para comercio y oficinas, los cuales son considerados como piezas habitables y por lo tanto tienen las mismas restricciones que los edificios para habitaciones vistos anteriormente. La especificación particular de "escaleras" es un poco mas rígida en estos.

El capítulo X trata sobre edificios destinados a la educación. Para poder otorgar licencia de construcción, ampliación, adapatación ó modificación para este tipo de edificios se requisito indispensable que previamente se apruebe su ubicación. La superficie total del terreno destinado a la construcción de edificios para la educación será por lo menos de cinco metros cuadrados por alumno. El número de alumnos se calculará de acuerdo con la capacidad total de las aulas. La capacidad de las aulas deberá calcularse a razón de un metro cuadrado por alumno, con una capacidad máxima de cincuenta alumnos. Las aulas deberán estar iluminadas y ventiladas por medio de ventanas a la vía pública o a patios y estas ventanas deberán abarcar por lo menos toda la longitud de uno de los muros mas largos. Los patios que sirvan para dar iluminación y ventilación a las aulas deberán tener por lo menos una dimensión de un medio de la altura del paramento y como mínimo tres metros. La iluminación artificial de las aulas será directa y uniforme. Estos edificios deberán tener un espacio para el esparcimiento físico de los alumnos con una superficie mínima equivalente a vez y media al área construida con fines diferentes del esparcimiento. Se exceptuan de esta obligación las escuelas especializadas. Toda escuela tendrá un local adecuado para enfermería, dotado con equipo de emergencia.

El capítulo XIII del Reglamento se refiere a los hospitales. Las dimensiones mínimas para los cuartos de enfermos, de los corredores y de los patios son las mismas restricciones que las vistas para edificios de habitación. Las dimensiones de las salas generales para enfermos se deben calcular en la misma forma que en los edificios para la educación. La instalación eléctrica general debe abastecerse, ademas de las del servicio público, con una planta particular con la capacidad necesaria.

El capítulo XIV referente a industrias en su artículo III obliga, antes de dar autorización para construir un edificio de este tipo, a que "previamente se apruebe su ubicación conforme a las disposiciones legales aplicables". La industria que por su importancia y por la naturaleza de sus actividades y desechos, impliquen riesgos se ubicarán fuera de la zona urbana; las que causen molestias, en zonas industriales y si las molestias son tolerables, en cualquier zona siempre que no existan prohibiciones o restricciones que lo impidan. El artículo 112 aun reserva la expedición de la licencia de construcción para este tipo de edificios a que "la Dirección General de Obras Públicas deberá cuidar que las construcciones satisfagan lo previsto en los reglamentos de medidas preventivas de accidente y de higiene del trabajo".

El capítulo XV se refiere a salas de espectáculos dando como primer requisito para otorgar la licencia "la aprobación previa de su ubicación y demas requisitos conforme a las disposiciones legales aplicables". Todas las salas destinadas a espectáculos deberán tener accesos y salidas directas a la vía pública ó comunicarse con ella por pasillos con anchuras mínimas dadas en función de las anchuras de todas las circulaciones que desalojen las salas por esos pasillos. Estos accesos y salidas se deben localizar de preferencia en calles diferentes. Toda sala de espectáculos debe tener por lo menos tres salidas. Deberán tener así mismo vestíbulos que comuniquen la sala con la vía pública ó con los pasillos que den acceso a esta. Ademas cada clase de localidad deberá tener un espacio para el descanso de los espectadores en los intermedios. Sobre las puertas a la vía pública se deberán poner marquesinas. Las taquillas para la venta de boletos no deben obstruir la circulación por los accesos ademas de localizarse en forma visible. La altura libre de la sala no será en ningún punto de menos de tres metros. El volumen de la sala se calculará a razón de dos y medio metros cúbicos por espectador. El artículo 119 solo permite la instalación de butacas y prohibe la de gradas en las salas de espectáculos. Ademas se reserva el derecho de revisión y "se ordenara el retiro de butacas de las zonas de visibilidad defectuosas". Las butacas se deberán fijar al suelo y ser de asientos plegadizos. En los muros de los pasillos no se permiten salientes a una altura menor de tres metros. La anchura de las puertas que comuniquen la salida con el vestíbulo, deberá permitir la evacuación de la sala en tres minutos. Cada piso o tipo de localidad con cupo superior a cien personas, debe tener por lo menos, ademas de las puertas antes vistas una salida de emergencia que comunique a la calle directamente ó por medio de pasajes independientes. Las hojas de las puertas deben abrirse al exterior. El artículo 123 prohibe terminantemente "que en los lugares destinados a la permanencia ó al transito del público,

haya puertas simuladas ó espejos que hagan aparecer el local con mayor amplitud que lo que realmente tenga". Las escaleras tendrán una anchura mínima igual a la suma de las anchuras de las puertas o pasillos a los que den servicio y construirse de materiales incombustibles. Cada piso debe tener por lo menos dos escaleras. Los escenarios, vestidores, bodegas, talleres, cuartos de máquinas y casetas de proyección deben estar aislados entre sí y de la sala, así mismo tendrán salidas independientes de la sala. Todas las salas de espectáculos deben tener ventilación artificial. El aire deberá ser tratado para obtener una cierta temperatura, húmedad y concentración de bioxido de carbono. Deben tener servicios sanitarios para cada localidad y precedidos de un vestíbulo. Las salas de espectáculos deben tener una instalación hidraúlica independiente para casos de incendio con una presión necesaria en toda la instalación para que el chorro de agua alcance el punto mas alto del edificio. Solo se autorizará el funcionamiento de las salas de espectáculos cuando los resultados de las pruebas de carga y de sus instalaciones sean satisfactorios. Esta autorización deberá recabarse anualmente.

El capítulo XVI referente a centros de reunión como casinos, cabarets, restaurantes, salas de baile o cualquier otro con uso semejante tiene disposiciones similares al capítulo XV para salas de espectáculos. Tambien el Capítulo XVII destinado a edificios para espectáculos deportivos y el capítulo XVIII a templos siguen poco mas ó menos las mismas disposiciones del XV.

El capítulo XIX se refiere a estacionamientos definiendolos como lugares "de propiedad pública privada destinado a guardar vehículos". Para otorgar licencia de construcción, ampliación ó modificación de lugares que se destinen total ó parcialmente a estacionamientos, se necesita la aprobación de su ubicación. Los estacionamientos deben tener carriles separados para la entrada y salida de los vehículos con una anchura mínima de dos metros y medio. Deben tener areas para el ascenso y descenso de personas, al nivel de las aceras, a cada lado de los carriles. La altura libre de cualquier punto no puede ser menor de dos metros con diez centímetros. Las rampas tendrán una pendiente máxima de quince por ciento y curvas con radio mínimo de siete y medio metros. Estas rampas estarán delimitadas por una guarnición. Las columnas y muros deberán tener una banqueto de protección. Si las areas de estacionamiento no estuvieran a nivel, los cajones se dispondrán en forma tal que en caso de que falle el sistema de frenos el vehículo quede - detenido en topes. Cuando no se construyan edificios para estacionamiento de vehículos sino solamente se utilice el terreno, este deberá pavimentarse y drenarse adecuadamente, contar con entradas y salidas independientes, tendrán delimitadas areas de circulación, contarán con topes para las ruedas, bardas propias en todos los linderos, casetas de control y servicios sanitarios. Este capítulo en su artículo 177 da una excepción "los estacionamientos privados no estan obligados a tener carriles separados, areas para ascenso y descenso de personas, servicios sanitarios y casetas de control".

El capítulo XXI; último del título segundo referente al proyecto arquitectónico; da una serie de niveles mínimos de iluminación en luxes, para las diferentes tipos de edificios.

El título tercero del Reglamento dispone las restricciones al diseño estructural. Todas las estructuras deben ser analizadas por los procedimientos reconocidos de — análisis elástico ó inelástico, siempre que se sujeten a los requisitos que señala el Reglamento. Pueden emplearse métodos de cálculo diferentes, pero el diseño deberá ser aprobado - por la dirección General de Obras Públicas. El diseño de estructuras especiales por sus caracterísiticas ó materiales requerirá aprobación especial de la misma Dirección.

El capítulo XXIII trata de cargas muertas y dá una tabla de pesos volumétricos a los cuales deberán sujetarse los diseños estructurales.

El capítulo XXIV sobre cargas vivas, también da una tabla de estas y l de cálculo no serán menores que las especificadas en dicha tabla. El propietario del e ficio sería el responsable de los perjuicios que podría ocasionar un cambio de destino de la construcción cuando produzca cargas mayores que las del diseño.

Capítulo XXI.- Cimentaciones. Este capítulo principia dividiendo el territorio del Distrito Federal en zonas de alta compresibilidad y de baja compresibilidad y dando en su artículo 191 la obligación de cimentar toda construcción o estructura. En — ningú caso se podrán construir cimientos sobre tierra vegetal, rellenos sueltos o deshech los cuales tendrán que ser removidos en su totalidad. La profundiad mínima de desplante requerida es de 50 cm. bajo la superficie del terreno, exceptuándose las construccione cimentadas directamente sobre roca.

El factor de seguridad mínima admisible contra falla del suelo por esfuerzo cortante será de 3. El tipo de cimentación elegido, así como su diseño y ejecució deberán asegurar que los movimientos verticales que ocurran durante la construcción del edificio y la vida del mismo no afecten su estabilidad ni la de construcciones vecinas y ademas no interfieran el bien funcionamiento de las instalaciones en la vía pública.

Los capítulos XXVI al XXX interesan a elementos de mampostería, estru turas de madera, de concreto, de metal y compuestas. En ellos se dan los esfuerzos pe misibles para los distintos elementos estructurales diseñados en estos diferentes materia Para estructuras de madera la calidad de la misma no podrá ser inferior a la de tercer También en estos mismos capítulos se dan las especificaciones para elementos de unió los diferentes estructuras: clavos, pernos, soldadura, remaches etc.

Termina este título tercero con los diseños por sismo y viento. Para si se clasifican los edificios por su destino en tres grupos y por su estructuración en tres tipos. De acuerdo con la clasificiación del edificio y de la zona de compresibilidad en la que vaya a ser construido puede obtenerse el coeficiente sísmico para el diseño. No es necesario considerar la acción simultanea del viento y del sismo. En estructuras cuya área cubierta exceda de 10,000 m^2 ó cuya altura exceda de 45 m. deberán instalarse deformímetros y oscilógrafos capaces de registrar con precisión movimientos intensos. Para el diseño por viento, las estructuras se analizarán suponiendo que puede actuar por lo menos según dos direcciones perpendiculares entre si. Asi como en el sismo, cuando una estructura exceda en altura los 45 m. se deberán instalar anemómetros capaces de registrar con precisión velocidades altas de viento.

El título cuarto se refiere a la ejecución de las obras. Da en sus artículos, una serie de tolerancias y procedimientos de construcción que serían mínimos para la buena ejecución de la obra.

En el título quinto se dan disposiciones para la conservación de predios y edificios, así mismo se limitan con un permiso especial los usos peligrosos, molestos o malsanos, considerándose como estos:

1.- Producción, almacenamiento, depósito, venta ó manejo de substancias ó de objetos tóxicos, explosivos, inflamables ó de fácil combustión.

2.- Excavación de terrenos, depósito de escombros ó basuras, exceso ó mala aplicación de cargas a las construcciones.

3.- Los que produzcan humedad, salinidad, corrosión, gases, humo, polvo, emanaciones, ruidos, trepidaciones, cambios sensibles de temperatura, malos olores u otros efectos perjudiciales ó molestos para las personas ó que puedan causar daño a las propiedades.

4.- Las demas que establecen el Código Sanitario y los Reglamentos respectivos.

Concluye el Reglamento de las Construcciones con su título sexto con disposiciones diversas tales como los derechos y obligaciones de los directores responsables de obras, propiedades de las licencias, inspecciones y un último capítulo en el cual se dictan los medios y sanciones para hacer cumplir el Reglamento.

4.- CRITERIOS ECONOMICOS PARA DETERMINAR LA EFICIENCIA DE UTILIZACION DE UN TERRENO.

Vamos a ver primeramente una serie de generalidades y de definiciones para entender con mas claridad algunos conceptos que usaremos para entrar al tema de los criterios económicos usuales para determinar la utilidad de un terreno.

Los bienes raices se adquieren pensando primordialmente en la renta que van a producir. En el trato de dichas propiedades, el valor tiende a ser prescrito por la cantidad, calidad y durabilidad de la renta neta imputable a la propiedad.

El valuador empieza su trabajo analizando la renta bruta económica. Esta renta en la cantidad el valor de renta razonable que la propiedad es capaz de producir, mas diversos y servicios, si los hay. El alquiler económico esta basado en la comparación de niveles de renta y puede ser mas o menos que el alquiler actual.

En la práctica, no puede esperarse que muchos edificios sean ocupados completo y continuamente, tampoco puede superarse que los pagos sean inmediatos y exactos, por lo tanto, se debe hacer una deducción por vacantes y/o cobros perdidos. Otra deducción importante a la renta son los gastos varios de operación, tales como impuestos, seguros, administración, servicios, personal, reparaciones, almacén para repuestos y cualquier otro gasto apropiado imprevisto.

Entendemos por "depreciación neta" a la diferencia entre la renta deducida por vacantes y los gastos de operación. Se conoce también como "recuperación neta" o como "flujo de caja". Es el verdadero punto de partida para el proceso de capitalización.

La capitalización es el proceso de convertir la depreciación neta en importe, bien dividiendo la renta en proporciones adecuadas o multiplicándola por un factor.

Excepto para propiedades rentadas a largo plazo, la practica actual es dividir la renta proporcionalmente.

La relación entre la renta neta antes de la recuperación y el valor total de la propiedad, se conoce como "contribución total". Es la relación ingreso-valor.

La contribución total incluye y mezcla una tasa de interés por la tierra, una tasa de interés por la construcción y una pensión por la recuperación de la construcción.

Por ejemplo, si una propiedad tiene una renta neta antes de la recuperación de $ 10,800.00 por año y se cotiza en el mercado en $ 120,000.00, la contribución total sería de 9% ya que 10,800.00 entre 120,000.00 es igual a 0.09. La tasa de interés es un por ciento, que no incluye una pensión por recuperación. Se aplica a los ingresos del terreno.

La tasa de capitalización sí incluye una pensión por recuperación. Se aplica a los ingresos de la construcción.

Tasa de intereses + tasa de recuperación = tasa de capitalización.

LLamamos "factor" al recíproco de una tasa. Hay publicadas tablas de factores, cada una de las cuales, tiene su propia esfera de utilidad y aplicación. Las tablas de factores mas frecuentemente usadas, son la "tabla Inwood" y la "tabla reversible".

Los procedimientos conocidos como "técnicas residuales" atacan el proceso de capitalización, con el uso de tasas ó factores.

El ingreso neto imputable a la propiedad, se trata deduciendo los intereses de la construcción y las cargas por recuperación y despues se capitaliza la renta residual para obtener una indicación del valor de la tierra conocido como "valor residual del terreno".

De la misma forma el ingreso ó renta neta se trata deduciendo primeramente los ingresos del terreno y despues capitalizando el ingreso residual a una tasa que incluye el interés de la construcción y su recuperación y obtenemos lo que se llama "valor residual de la construcción".

Para obtener el "valor residual de la propiedad" se siguen dos caminos:

1.- El ingreso neto se trata con una sola tasa, la cual mezcla un por ciento por el terreno, otro por la construcción y otro por la recuperación. En otras palabras, la recuperación neta anterior, es capitalizada con una tasa que cubre todo.

2.- El ingreso neto es capitalizado por aplicación de un factor apropiado de anualidad, al cual se le añade el valor actual del valor estimado de aquella parte de la propiedad, la cual reverterá al concluir la anualidad.

En el método de capitalización llamado"línea recta", el tratamiento usua es con la técnica del valor residual de la construcción.

La capitalización directa y los métodos "Ellwood" emplean el valor residual de la propiedad.

Veamos un ejemplo del proceso de capitalización:

Consideremos una propiedad con un ingreso de $ 20,000.00 por año y un "flujo de caja" que se espera sea de $ 10,800.00 por año. Consideremos un valor independiente del terreno de $ 20,000.00 y una vida económica de 33 años. Vamos a tratar el problema por varios métodos.

a).- Con el método de capitalización directo, usando 9% como la tasa aplicable o conveniente que cubre todo:

Flujo de caja ó depreciación neta anterior................	$ 10,800.00 / año
Capitalizando a 9%	÷ 0.09
Valor indicado..	$ 120,000.00

b).- Con el método de "línea recta":

La tasa de recuperación se añade a la tasa de interés, debido a que las instalaciones de recuperación, son recibidas cada año en importes iguales:

Ingreso bruto..................................	$	20,000.00 / año
Gastos..	$	9,200.00 / año
Recuperación neta anterior.........................	$	10,800.00 / año
Imputable al terreno 6½% de $ 20,000.00	$	1,300.00 / año
Neto, ganancia del capital (para restituirse al capital)	$	9,500.00 / año
Capitalizando a 9½% (6½% interés + 3% recuperación correspondiente a 33 años de vida económica) valor de la construcción..............................	$	100,000.00
Mas terreno..............................	$	20,000.00
Total.	$	120,000.00

c).- Por el método de hipoteca legal:

Flujo de caja (depreciación neta anterior)	$	10,800.00 / año.
Hipoteca de $ 80,000.00, 20 años, 6%, 8.604 deuda constante a cubrir (de tablas de hipotecas, 12 x pago mensual)................................	$	6,880.00 / año.
Neto por equidad..............................	$	3,920.00 / año.
Capitalizando 10% para retorno equitativo, considerado como suficiente para atraer el riesgo del capital..........	$	39,200.00 / año.
Añadiendo hipoteca..............................	$	80,000.00 / año.
Total	$	119,200.00

d).- Por el método de anualidades:

Supongamos permanece 17 años en arriendo a $ 10,800.00 por año y un arriendo al final de $ 20,000.00 y $ 50,000.00 por la construcción, total - - - - $ 70,000.00.

Valor presente de $ 10,800.00/año a 6½%, factor de 17 años 10.110..	$109,188.00
Valor presente de $ 70,000.00 devolución en 17 años a 6½ %, factor 0.3428..............................	$ 23,996.00
Total	$ 133,184.00

e).- Por el concepto Ellwood:

La Renta neta es valuada por aplicación de una tasa de capitalización que cubre todo. Esta tasa es sacada de un libro de tablas o bien calculada por una fórmula en aquellos casos en que no se encuentra directamente en tablas de tasas.

En el ejemplo expuesto se podría pensar que los datos son un proyecto razonable en los 8 años próximos. Se vendería por 15% menos al final de este periodo, posiblemente aún 20% menos. El financiamiento de hipoteca es obtenible a 65% del valor, a 6% de interés, con una amortización de 20 años.

Tasa Ellwood con 15% de depreciación = 8.89 %

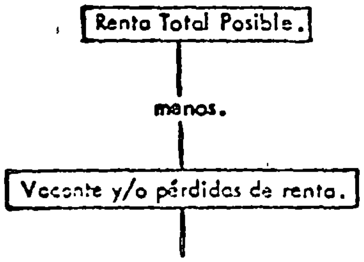
10,800.00/año ÷ 0.0389 = $ 121,500.00

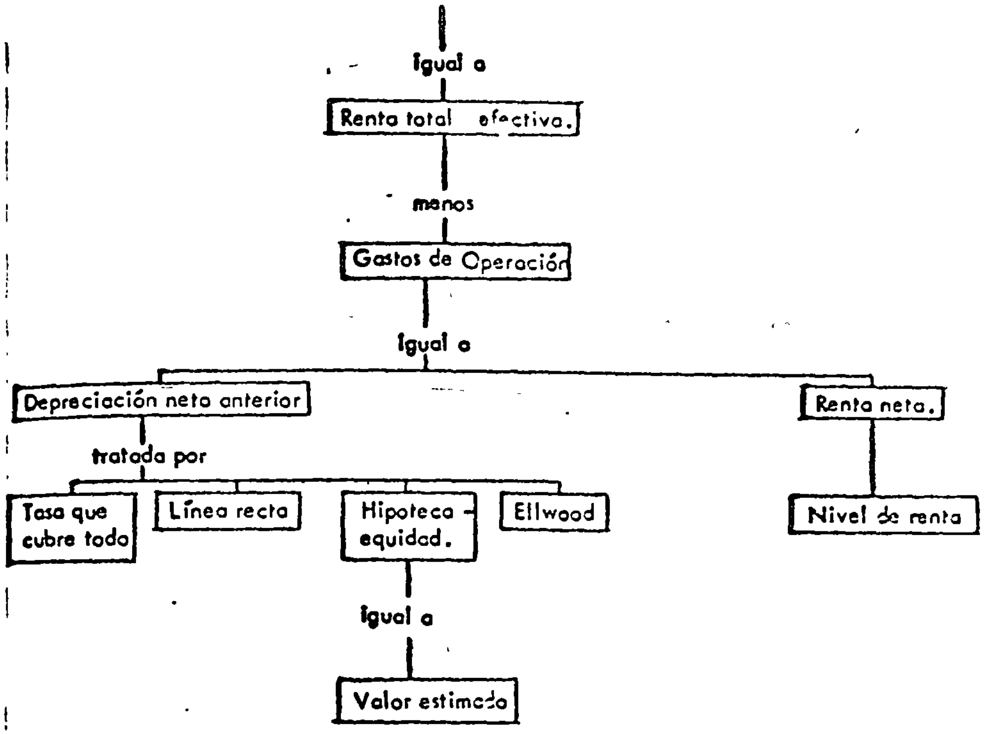
Tasa Ellwood con 20% de depreciación = 9.32 %

10,800.00/año ÷ 0.0932 = 115,900.00

Como vemos, no hay un solo "camino recto" para capitalizar la renta. Los métodos aceptables comunmente tienen en sí, cierta suposiciones variables. Por ejemplo, la capitalización directa con la tasa que cubre todo, no estipula una vida económica, ni diferencía que parte es tierra y que parte es construcción. Es simple y convincente cuando hay suficientes transacciones de mercado abierto para probar que la tasa es correcta. El método de línea recta con la técnica del valor residual de construcción, postula una vida económica, diferencía la tierra y la construcción en suma proporciona una renta neta gradual. Puede parecer teórico, pero en la práctica, provee unas pautas muy satisfactorias. El método hipoteca-equidad, es el más típico usado por los inversionistas y la cantidad y tipo de hipoteca que pueden obtener, frecuentemente determinará el precio que pagarán. Los réditos de equidad son asunto de observación y juicio, corrientemente entre 8 y 12% ó más. Lo mejor del método es la observación de las reacciones entre comprador y vendedor. El procedimiento de anualidades presume que hay una renta neta asegurada por un periodo claramente largo, lo cual, afecta favorablemente la calidad y durabilidad de la renta . Por lo tanto, la propiedad vale más que de otra manera. El concepto Ellwood, refleja los mismos factores que el método hipoteca-equidad. Surge un juicio adicional que es, si la propiedad se depreciará en el futuro mas rapidamente que la amortización de la hipoteca, lo cual significa, que la equidad puede ó no incrementarse en valor.

Podemos ver el proceso de capitalización mas objetivamente en el siguiente diagrama:





Tenemos dos formas de determinar la eficiencia de utilización de un terreno. Por medio del procedimiento llamado tradicional y por el proceso del valor residual del terreno.

El procedimiento tradicional consiste en seleccionar una utilización de entre todas las que se crean factibles. Elaborar un proyecto para esta utilización. Estimar la inversión necesaria que se requerirá para construir el proyecto y sumándole a esta cantidad estimada, el valor del terreno, obtener la inversión total en el inmueble. Después hay que estimar la renta mensual que se espera obtener del inmueble. Con esto, se comparan las dos cantidades obtenidas : la renta mensual y la inversión total. Por último, se aprueba el proyecto si la renta mensual esperada representa una fracción satisfactoria (p) respecto a la inversión total, ó bien, se modifica dicho proyecto, ó se elabora uno nuevo, si la renta mensual esperada no representa una fracción satisfactoria (p) de la inversión total,

Si la renta mensual esperada representa una fracción satisfactoria (p) de la inversión total y se tiene un proyecto de utilización homogenea podemos expresar esto en la siguiente fórmula:

$$x\,Ar = p\,(yAc + VAt) \text{ - - - - - - - - - - - - (1)}$$

en la cual:
x = renta mensual por M2 de la utilización U
y = valor de la construcción por M2 para la utilización U
V = valor de terreno por M2
Ar = Area rentable
Ac = area construidc
At = area del terreno disponible para la utilización U.

Observando la fórmula (1) podemos ver que la eficiencia del proyecto, está medida por p y podríamos concluir, que mientras mayor sea p, mayor sería la eficiencia del proyecto, lo cual es falso: Si la fórmula (1) se despeja a V.

$$V = \frac{\frac{xAr}{P} - yAc}{At} \text{ - - - - - - - - (2)}$$

En esta fórmula podemos ver que si (xAr), (yAc) y At son fijas, a medida que p es mayor, V resulta menor, o sea, que si queremos un valor mayor de p, lo obtenemos a costa de reducir el valor del terreno.

Cuando el proyecto se trata de varias utilizaciones U_1, U_2, U_n la fórmula (2) se escribirá de la siguiente manera:

$$V = \frac{\frac{X_1 Ar_1}{P} + \frac{X_2 Ar_2}{P} + \frac{X_n Ar_n}{P} - y_1 Ac_1 + y_2 Ac_2 + y_n Ac_n}{At}$$

ó bien abreviadamente:

$$V = \frac{\sum_{j=1}^{n} \frac{x_j Ar_j}{P} - \sum_{j=1}^{n} y_j Ac_j}{At} \text{ - - - - - - - - - (2)}$$

En el proceso del valor residual del terreno, la medida de la eficiencia d un proyecto de utilización de un terreno, está dada por el llamado "valor residual del terreno" que representamos con la letra V y definimos de la siguiente forma:

$$V = \frac{\text{(Valor presente de la renta capitalizada durante la vida económica de la utilización)} - \text{(Valor de la construcción).}}{\text{Area del terreno.}}$$

Poniendo esta definición en fórmulas:

Para la utilización homogenea:

$$V = \frac{\frac{xAr}{P} - yAc}{At} \text{ - - - (3)} \qquad P = \frac{ic + ia}{12(1 - \alpha)} \text{ - - - - - - (4)}$$

Para una utilización múltiple:

$$V = \frac{\sum_{j=1}^{n} \frac{x_j Ar_j}{P_j} - \sum_{j=1}^{n} y_j Ac_j}{At} \text{ - - - - - (3')} \qquad P_j = \frac{ic_j + ia_j}{12(1 - \alpha_j)} \text{ - - - - - (4'}$$

En las cuales x, y, Ar, Ac, y At tienen el mismo significado visto anteriormente.

ic = tasa de interés sobre el capital proveniente de la renta
ia = tasa de amortización de la inversión en la utilización
$ic + ia$ = tasa de capitalización.
α = factor de deducciones a la renta total, definido por:

deducciones = α por renta total

Vamos a ver las relaciones que hay entre el método tradicional y el del - sidual del terreno.

Comparando la fórmula (2) con las fórmulas (3) y (4) vemos que son de - - structura y que dan el mismo resultado si y solamente si p en (2) se hace igual a o por (4). p es una medida de la tasa de capitalización de la renta neta men-

Comparando la Fórmula (2') con la fórmulas(3) y (4') vemos que son de - ura similar y que dan el mismo resultado si se elige p en(2') de manera que:

$$\sum_{j=1}^{n}\left(\frac{x_j A r_j}{p}\right)=\sum_{j=1}^{n}\left(\frac{x_j A r_j}{p_j}\right)$$

tanto:

$$p=\frac{\sum_{j=1}^{n}(x_j A r_j)}{\sum_{j=1}^{n}\frac{x_j A r_j}{p_j}}$$

e cumple si $p = p_1 = p_2 = \cdots = p_n$ que en general son diferentes - sí.

La mejor utilización de un determinado terreno es un problema de decisión e le presenta al inversionista. El debe decidir que clase de utilizaciones desea ha- de que calidad deben ser, qué área destinar a cada una de las utilizaciones, si el que quiera darle al terreno es múltiple y que renta fijar a cada una de las utilizacio- para lograr que el valor residual del terreno sea el máximo. Como ya hemos visto, tilizaciones tienen sus límites, ya que se tienen restricciones.

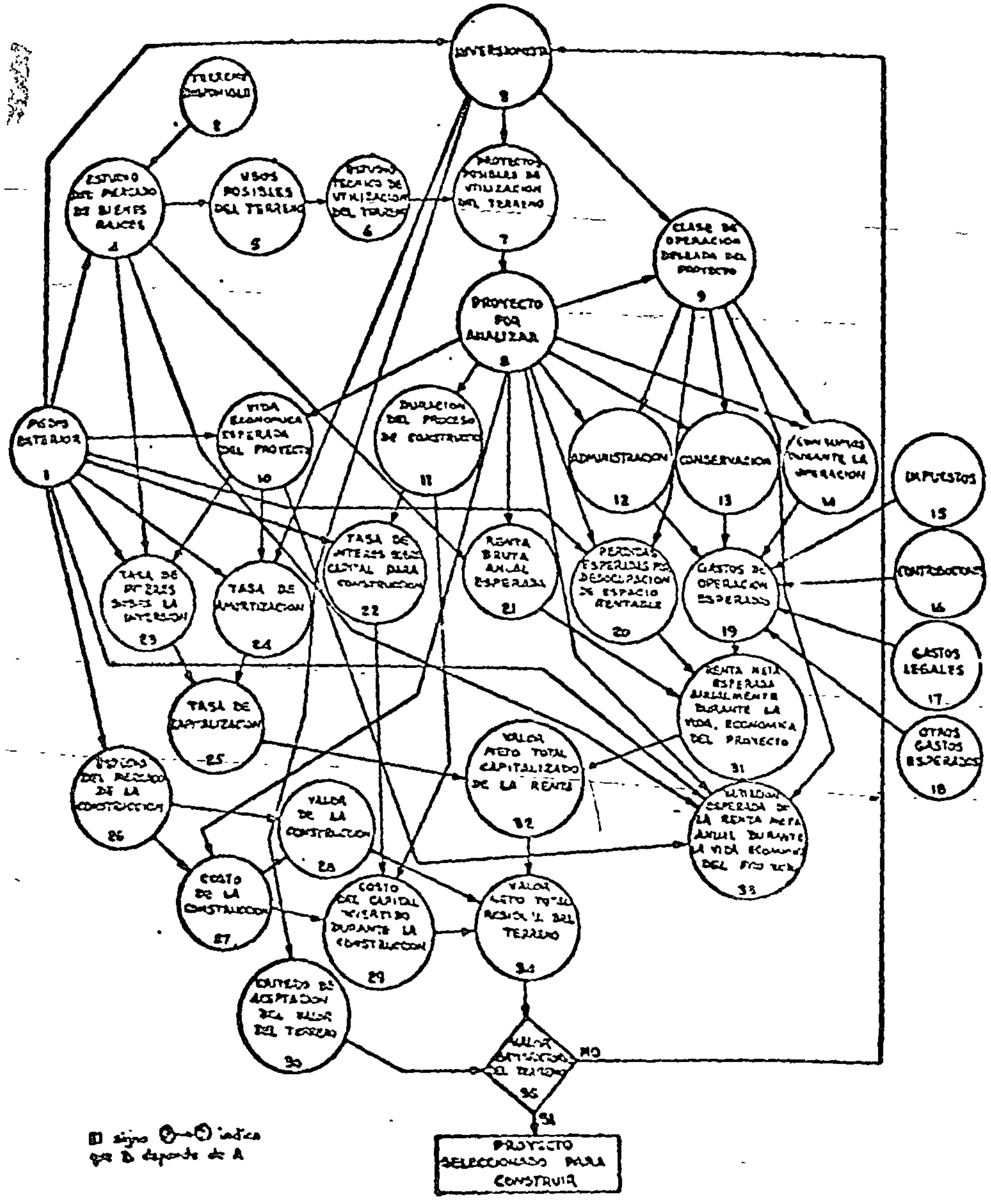
Para resolver el problema de la determinación de la mejor utilización de

un terreno hay dos métodos dentro del método general del valor residual del terreno: por tanteos y por programación matemática. El primero, se emplea con buenos resultados por valuadores expertos. La aplicación de la programación matemática al problema, es nueva, presentada por primera vez ante la II Convención Nacional de Valuación, reunida en la ciudad de Guadalajara, Jal. en Septiembre de 1964, por el Doctor en ciencias, Melchor Rodríguez Caballero.

El método iterativo consiste, en la elaboración de varios proyectos de utilización factible, teniendo en cuenta las restricciones existentes. Se selecciona uno de los proyectos para analizarlo. Se fijan rentas a las utilizaciones de este proyecto y se determina la renta neta mensual esperada. Se estima la vida económica del proyecto. Se selecciona un criterio para amortizar la inversión en el proyecto. Se fija una tasa de interés para el capital proveniente de las rentas. Se determina el valor presente total de la renta neta capitalizada durante la vida económica del proyecto. Se estima el valor total de la construcción. Con estos datos se aplica la fórmula, para obtener el valor residual del terreno. Si este valor resulta satisfactorio, se acepta el proyecto como posible. Se repiten todos los pasos para cada uno de los proyectos elaborados.

Con todos los datos obtenidos, se comparan los valores y se selecciona como proyecto óptimo, aquel que de lugar al mayor valor residual del terreno ó bien se selecciona como proyecto óptimo a cualquiera de los proyectos factibles, si todos ellos conducen al mismo valor residual del terreno.

Podemos ver objetivamente el método iterativo en el siguiente esquema:



El signo A→B indica que B depende de A

El método de tanteos es relativamente fácil de aplicar pero tiene dos limitaciones importantes, la primera es que se requiere la elaboración de varios proyectos, lo cual es costoso, y la segunda, derivada de la primera, es que no permite considerar todas las combinaciones posibles de utilizaciones factibles, por lo cual, se puede llegar a un resultado que puede no ser el óptimo de utilización del terreno.

Para una mejor comprensión de la aplicación de la programación matemática a la determinación de la mejor utilización de un terreno, vamos a dividir su estudio en dos casos:

Caso I.- Utilizaciones exlcuyentes.- Cuando solo se quiere una utilización factible del terreno, se aplican las fórmulas (3) y (4). Substituyendo ésta en aquella:

$$V = \frac{12\,(1-\alpha)}{ic + ia}\ \frac{Ar}{At}\ x - \frac{Ac}{At}\ y \quad \text{- - - - - - - -} \quad (5)$$

Llamando "z" a la relación de $\frac{Ac}{At}$

y "β" a la relación de $\frac{Ar}{Ac.}$

Considerando el producto "βz" = $\frac{Ar}{At}$

y substituyendo estos valores en la fórmula (5), obtenemos la fórmula básica del valor residual del terreno por metro cuadrado:

$$V = (Kx - y)z \quad \text{- - - - -} \quad (6)$$

en la cual $K = \frac{12\,(1 - \alpha)\,\beta}{ic + ia}$

Este parámetro "K" es adimensional; es un factor de capitalización de la renta mensual por metro cuadrado de utilizacióny es una característica intrínseca de la utilización considerada. El parámetro "z" (también adimensional), es un factor de utilización del terreno, siempre menor que la unidad ó cuando mucho igual a ella. Para cualquier valor de este parámetro " z ", el factor (Kx - y) representa la contribución de cada metro cuadrado construido al valor residual del terreno por metro cuadrado.

Quedando definida la calse de utilización, queda definido el parámetro "K" y solo falta estimar los valores de x, y, z . Estos valores deben cumplir ciertas restricciónes.

El valor de la renta mensual por metro cuadrado "x", no debe exceder de un cierto valor (al que llamaremos "b") y que se fija a través de un estudio del mercado de rentas de bienes raices y a partir de la clase, calidad y localización de la utilización. Representando matemáticamente este concepto: $x \leq b$

El valor de la construcción por metro cuadrado "y", no debe ser menor de un cierto valor (al que llamaremos "c") y que se fija a través de un estudio del mercado de la construcción y a partir, asimismo, de la clase, calidad y localización de la utilización. Expresándolo matemáticamente:

$$y \geq c$$

Por último, el valor del factor de utilización del terreno " z ", no debe ser mayor de un cierto valor (al que llamaremos "d") fijado por requisitos funcionales y reglamentarios para la clase, calidad y localización de la utilización. En términos matématicos:

$$z \leq d$$

Estas tres restricciones vistas anteriormente, se las llama restricciones básicas.

Habiendo solamente una utilización factible para un cierto terreno y ya determinado "K", el problema de encontrar la mejor utilización del terreno es un problema de maximización en el cual hay que determinar los valores x, y, z que hacen máximo a V de manera que se cumplan las restricciones básicas. O sea:

$$\text{Max.} \quad V = (Kx - y)z$$

de modo que:

$$x \leq b$$

$$y \geq c$$

$$z \leq d$$

Este probelma puede resolverse usando la técnica denominada "programación cuadrática", técnica que ha sido estudiada extensamente en los últimos 15 años y ha sido aplicada a cantidad de problemas de dirección científica de empresas.

Sise elige "z" de manera que se cumpla la restricción $z \leq d$ la función $V = (Kx - y) z$ resulta lineal y en este caso, se puede usar la técnica llamada "programación lineal" a la resolución del problema.

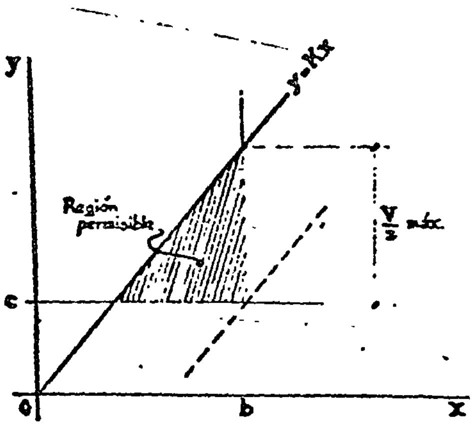
Siendo de gran interés este problema, vamos a verlo en detalle:
Si los valores "K" y "z" son conocidos, la pareja de valores "x,y" puede representarse por un punto de un plano cartesiano ortogonal. A todas aquellas parejas de valores (x, y) que hacen que V sea igual a cero, las llamamos "puntos de equilibrio". Así:

$$V = (Kx - y)\, z = 0$$

de donde $y = Kx$

que es la ecuación de una recta a la que llamaremos en consecuencia, "linea de equilibrio".

Representando todo esto gráficamente:



De la gráfica podemos observar, que para todos los puntos de la línea de equilibrio, el valor de construcción es igual al valor capitalizado de la renta. Que para los puntos siguados abajo de la línea de equilibrio, el valor de construcción es menor que el valor capitalizado de la renta y por lo tanto el valor residual del terreno es positivo. Contrariamente, en los puntos situados arriba de la línea, el valor de construcción es mayor que el valor capitalizado de la renta y en consecuencia el valor residual del terreno es negativo.

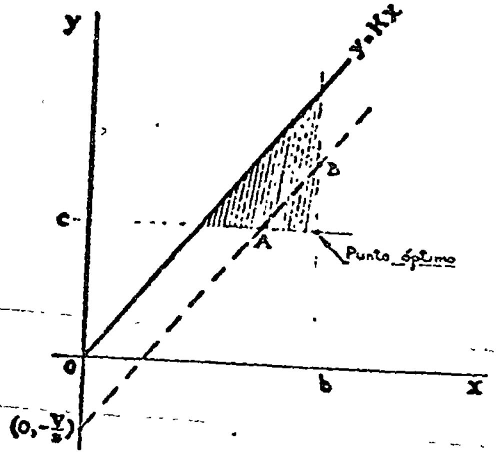
Es fácil ver también que " $x = b$ " es una recta perpendicular al eje "x" y que pasa por el punto (b,o). Todos los puntos a la izquierda de esta rectaserían los — " $x \leq b$ " . Asimismo " $y = c$ " es una recta perpendicular al eje "y" y que pasa por el punto (o, c). Todos los puntos arriba de esta recta serían los " $y \geq c$ ".

Por lo tanto, todos los puntso (x, y) para los cuales el valor residual del terreno $V \geq 0$ de manera que $x \leq b$ y $y \geq c$ deben encontrarse en la región asciurado en la figura, que llamamos "región permisible" y que incluye las fronteras.

Si ahora deseamos determinar cuales son los puntos (x,y) para los que "V" adquiere algún cierto valor determinado, despejamos "y" de la ecuación (6).

$$y = Kx - \frac{V}{z}$$

Siendo " $\frac{V}{z}$ " un valor definido y "K" es la misma, esta ecuación se cumple para los puntos de una recta paralela a la línea de equilibrio y que pasa por el punto $(o, - \frac{V}{z})$



Los puntos de esta recta que se encuentran en el segmento $\overline{AB}$ dentro de la región permisible, son los únicos para los cuales $x \leq b$, $y \geq c$. O sea, todas las parejas de valores (x, y) que corresponden a los puntos del segmento $\overline{AB}$ son soluciones del problema. Prácticamente, esto permite determinar la calidad de la construcción permisible para valores conocidos de la renta y del terreno, y determinar la renta permisible para valores conocidos del terreno y de la construcción.

De todo lo visto anteriormente, podemos llegar a la conclusión de que el valor máximo de "V" se tiene para el punto ($x = b$, $y = c$) ó sea para el punto al que le corresponde la mayor renta permisible con el menor valor de construcción permisible.

Dentro del Caso I de utilizaciones excluyentes que estamos viendo, podemos dividir su exposición en dos subcasos: cuando se tiene una sola utilización factible y cuando se tienen "N" utilizaciones factibles mutuamente excluyentes.

Vamos a ver el primer subcaso, en el cual tenemos solamente una utilización factible y no se conoce "z". En este problema, como en todos los que veremos, se trata de maximizar el valor residual del terreno.

Partimos de conocer los valores K, b, c, d. Como ya hemos visto antes, se requiere la aplicación de técnicas de programación no lineal.

Se usará el teorema de Kuhn-Tucker.

La función de Lagrange que se asocia al problema es:

$$L(x,y,z,\lambda,\mu,\nu) = (Kx - y)z + \lambda(b - x) + \mu(y - c) + \nu(d - z) \text{ - - - - - - - - } (7)$$

en la cual λ, μ, ν son parámetros no negativos, denominados multiplicadores de Lagrange y que se tienen que determinar. Para el punto óptimo $(x = X, y = Y, z = Z, \lambda = L, \mu = M, \nu = N)$ se cumplen las siguientes relaciones:

$$\left(\frac{\partial L}{\partial x}\right)_{op} = KZ - L \leq 0 \qquad \text{si vale} <, \quad X = 0 \text{ - - - - - - - - - } (7_1)$$

$$\left(\frac{\partial L}{\partial y}\right)_{op} = -Z + M \leq 0 \qquad \text{si vale} <, \quad Y = 0 \text{ - - - - - - - - - } (7_2)$$

$$\left(\frac{\partial L}{\partial z}\right)_{op} = KX - Y - N \leq 0 \qquad \text{si vale} <, \quad Z = 0 \text{ - - - - - - - - - } (7_3)$$

$$\left(\frac{\partial L}{\partial \lambda}\right)_{op} = b - X \geq 0 \qquad \text{si vale} >, \quad L = 0 \text{ - - - - - - - - - } (7_4)$$

$$\left(\frac{\partial L}{\partial \mu}\right)_{op} = Y - c \geq 0 \qquad \text{si vale} >, \quad M = 0 \text{ - - - - - - - - } (7_5)$$

$$\left(\frac{\partial L}{\partial \nu}\right)_{op} = d - Z \geq 0 \qquad \text{si vale} >, \quad N = 0 \text{ - - - - - - - - } (7_6)$$

En este problema, solamente tiene interes la siguiente clase de soluciones:

$$X > 0, \; Y > 0, \; Z > 0$$

Por lo tanto, los símbolos de desigualdad en las ecuaciones (7) deben suprimirse y obtenemos:

$$KZ - L = 0$$

$$-Z + M = 0$$

$$KX - Y - N = 0$$

$$b - X = 0$$

$$Y - c = 0$$

$$d - Z = 0$$

relacionándolas encontramos:

$$L = Kd \qquad x = b$$

$$M = d \qquad Y = c \qquad V\,opt. = (Kb - c)\,d \text{ - - - - - - - - - - - - } (8)$$

$$N = Kb - c \qquad Z = d$$

De esto podemos concluir que en el punto óptimo (X, Y, Z)

$$\frac{\partial V_{op}}{\partial b} = Kd \text{ - - - - - - - - - - - - } (a)$$

$$\frac{\partial V_{op}}{\partial c} = -d \text{ - - - - - - - - - - - } (b)$$

$$\frac{\partial V_{op}}{\partial d} = Kb - c \text{ - - - - - - - - - - - } (c)$$

Estas igualdades tienen la siguiente interpretación:

a).- A un incremento Δb en la renta límite, corresponde un incremento $V\,op. = (Kd)\,\Delta b$ positivo en el valor residual del terreno.

b).- A un incremento Δc en el costo límite, corresponde un decremento $V\,op. = (-d)$ en el valor residual del terreno.

c).- A un incremento Δd en el factor de utilización del terreno, corresponde un inc mento $V\,op. = (Kb - c)\,\Delta d$ en el valor residual del terreno.

La conclusión obvia, es que para lograr el valor residual máximo del te rreno, (x,y,z) deben tomar sus valores límites respectivos.

Veamos ahora, el segundo subcaso en el cual tenemos "N" utilizaciones factibles mutuamente excluyentes.

Vamos a designar estas utilizaciones con los símbolos $U_1, U_2, \ldots U_n$ y los valores correspondientes con el índice respectivo. Teniendo los siguientes datos:

Utilización U_1	Utilización U_2	....	Utilización U_n
K_1	K_2	....	K_n
$X_1 \leq b_1$	$x_2 \leq b_2$	....	$X_n \leq b_n$
$y_1 \geq c_1$	$y_2 \geq c_2$	....	$y_n \geq c_n$
$z_1 \leq d_1$	$z_2 \leq d_2$	....	$z_n \leq d_n$

Empleando estos valores y el resultado obtenido en la ecuación (8) calculamos los valores residuales máximos del terreno con cada una de las utilizaciones factibles:

$$V_1 \text{ op.} = (K_1 b_1 - c_1)\, d_1$$

$$V_2 \text{ op.} = (K_2 b_2 - C_2)\, d_2$$

....

$$V_n \text{ op.} = (K_n b_n - c_n)\, d_n$$

Comparando estos valores se determina el valor máximo de "V". Pueden ocurrir dos casos:

1).- Hay un solo valor V_o mayor que todos los demas. En este caso la mejor utilización es la V_o y las condiciones bajo las cuales se logra son $x_o = b_o$, $y_o = c_o$, $z_o = d_o$

2).- Hay dos o mas valores iguales "V" mayores que todos los demas. En este caso las utilizaciones óptimas del terreno son estas.

Caso II.- Utilizaciones no excluyentes.- Asi como en el Caso I, vamos a dividir este caso II, en dos subcasos, uno para dos utilizaciones factibles no excluyen y otro para "N" utilizaciones factibles no excluyentes.

En el caso de dos utilizaciones factibles no excluyentes la expresión del valor residual del terreno toma la forma:

$$V = (K_1 x_1 - y_1)\, z_1 + (K_2 x_2 - y_2)\, z_2$$

y las restricciones básicas serían:

$$x_1 \leq b_1 \qquad\qquad x_2 \leq b_2$$

$$y_1 \geq c_1 \qquad\qquad y_2 \geq c_2$$

en cuanto a "z" puede tomar cualquiera de las siguientes formas:

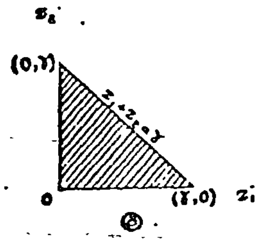
$$z_1 + z_2 \leq \gamma \text{ ----------- } a$$

$$\begin{aligned} &z_1 + z_2 \leq \gamma \\ &\quad z_1 \leq d_1 \,, \quad d_1 \leq \gamma \text{ --- } b \end{aligned}$$

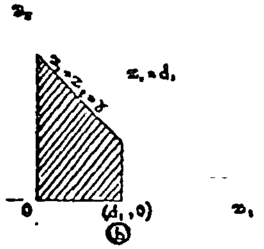
$$\begin{aligned} &z_1 + z_2 \leq \gamma \\ &\quad z_2 \leq d_2 \,, \quad d_2 \leq \gamma \text{ --- } c \end{aligned}$$

$$\begin{aligned} &z_1 + z_2 \leq \gamma \\ &\quad z_1 \leq d_1 \,, \quad d_1 \leq \gamma \\ &\quad z_2 \leq d_2 \,, \quad d_2 \leq \gamma \end{aligned} \text{ --- } d$$

Representando a z_1 y z_2 como coordenadas de un punto en un plano tesiano ortogonal, las restricciones anteriores quedan representados por las siguientes giones:



ⓐ



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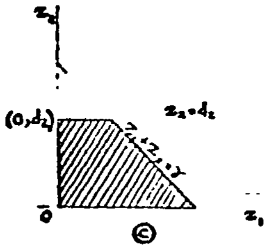

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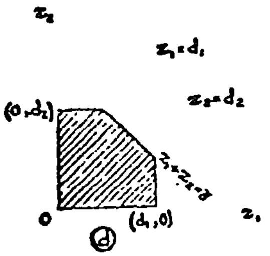

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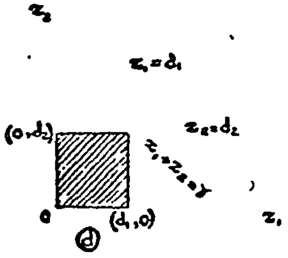

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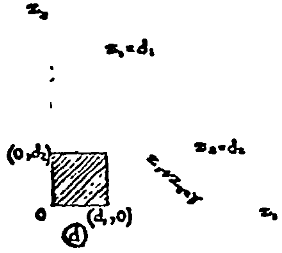

ⓓ

Para este caso, el problema general de la determinación de la mejor utilización del terreno se puede plantear la forma de encontrar los valores (x_1, y_1, z_1) de tal modo que :

$$\text{Max.}\ V = (K_1\ x_1 - y_1)\ z_1 + (K_2\ x_2 - y_2)\ z_2$$

con las restricciones:

$x_1 \leq b_1$

$x_2 \leq b_2$

$y_1 \geq c_1$

$y_2 \geq c_2$

$z_1 \leq d_1 \quad , \quad d_1 \leq \gamma$

$z_2 \leq d_2 \quad , \quad d_2 \leq \gamma$

$z_1 + z_2 \leq \gamma$

Aplicando el teorema de Kuhn-Tucker y formando la función de Lagrange:

$$\begin{aligned} L(x_1, x_2, y_1, y_2, z_1, z_2, \lambda_1, \lambda_2, \mu_1, \mu_2, \nu_1, \nu_2, \nu_3) = {} & (K_1\ x_1 - y_1)\ z_1 + \\ & + (K_2\ x_2 - y_2)\ z_2 + \\ & + \lambda_1(b_1 - x_1) + \\ & + \lambda_2(b_2 - x_2) + \\ & + \mu_1(y_1 - c_1) + \\ & + \mu_2(y_2 - c_2) + \\ & + \nu_1(d_1 - z_1) + \\ & + \nu_2(d_2 - z_2) + \\ & + \nu_3(\gamma - z_1 - z_2) \end{aligned}$$

Llamando a $(X_1, X_2, Y_1, Y_2, Z_1, Z_2, L_1, L_2, M_1, M_2, N_1, N_2, N_3)$ punto óptimo, las condiciones necesarias para la existencia de este son:

$\left[\frac{\partial L}{\partial x_1}\right]_{op} = K_1\ Z_1 - L_1 \leq 0$ si vale $<$, $X_1 = 0$

$\left[\frac{\partial L}{\partial x_2}\right]_{op} = K_2\ Z_2 - L_2 \leq 0$ si vale $<$, $X_2 = 0$

$\left[\frac{\partial L}{\partial y_1}\right]_{op} = -Z_1 + M_1 \leq 0$ si vale $<$, $Y_1 = 0$

$\left[\frac{\partial L}{\partial y_2}\right]_{op} = -Z_2 + M_2 \leq 0$ si vale $<$, $Y_2 = 0$

$\left[\frac{\partial L}{\partial z_1}\right]_{op} = K_1\ X_1 - Y_1 - N_1 - N_3 \leq 0$ si vale $<$, $Z_1 = 0$

$\left[\frac{\partial L}{\partial z_2}\right]_{op} = K_2\ X_2 - Y_2 - N_2 - N_3 \leq 0$ si vale $<$, $Z_2 = 0$

$\left[\frac{\partial L}{\partial \lambda_1}\right]_{op} = b_1 - X_1 \geq 0$ si vale $>$, $L_1 = 0$

$\left[\frac{\partial L}{\partial \lambda_2}\right]_{op} = b_2 - X_2 \geq 0$ si vale $>$, $L_2 = 0$

$\left[\frac{\partial L}{\partial \mu_1}\right]_{op} = Y_1 - c_1 \geq 0$ si vale $>$, $M_1 = 0$

$\left[\frac{\partial L}{\partial \mu_2}\right]_{op} = Y_2 - c_2 \geq 0$ si vale $>$, $M_2 = 0$

$\left[\frac{\partial L}{\partial \nu_1}\right]_{op} = d_1 - Z_1 \geq 0$ si vale $>$, $N_1 = 0$

$\left[\frac{\partial L}{\partial \nu_2}\right]_{op} = d_2 - Z_2 \geq 0$ si vale $>$, $N_2 = 0$

$\left[\frac{\partial L}{\partial \nu_3}\right]_{op} = \gamma - Z_1 - Z_2 \geq 0$ si vale $>$, $N_3 = 0$

Para este problema hay tres clases de soluciones:

1.- $Z_1 = 0$ $\quad Z_2 > 0$
2.- $Z_1 > 0$ $\quad Z_2 = 0$
3.- $Z_1 > 0$ $\quad Z_2 > 0$

Solución 1.- Haciendo las substituciones necesarias:

$L_1 = 0$

$K_2 Z_2 - L_2 = 0$

$M_1 = 0$

$-Z_2 + M_2 = 0$

$K_1 X_1 - Y_1 - N_1 - N_3 < 0$

$b_1 - X_1 > 0$

$b_2 - X_2 = 0$

$Y_1 - c_1 > 0$

$Y_2 - c_2 = 0$

$d_1 > 0$

$d_2 - Z_2 = 0$

$\gamma - Z_2 \geq 0$

relacionándolas tenemos:

$L_1 = 0 \qquad X_1 < b_1$

$L_2 = K_2 Z_2 \qquad X_2 = b_2$

$M_1 = 0 \qquad Y_1 > c_1$

$M_2 = Z_2 \qquad Y_2 = c_2$

$N_1 = 0 \qquad Z_1 = 0$

$N_2 = K_2 X_2 - Y_2 \qquad Z_2 = d_2$

$N_3 = 0$

y podemos concluir:

$K_1 b_1 - c_1 < 0$

$X_2 = b_2$

$Y_2 = c_2$

$Z_2 = d_2$

$V_{opt} = (K_2 b_2 - c_2)\, d_2$

de donde:

$$\frac{\partial V_{op}}{\partial b_2} = K_2 d_2$$
$$\frac{\partial V_{op}}{\partial c_2} = -d_2$$
$$\frac{\partial V_{op}}{\partial d_2} = K_2 b_2 - c_2$$

solución 2.- Por un proceso similar a la solución 1 llegamos a las cosiones:

$K_2b_2 - c_2 < 0$

$X_1 = b_1$

$Y_1 = c_1$

$Z_1 = d_1$

$V_{opt} = (K_1b_1 - c_1)\, d_1$

de donde:

$$\frac{\partial V_{op}}{\partial b_1} = K_1 d_1$$

$$\frac{\partial V_{op}}{\partial c_1} = -d_1$$

$$\frac{\partial V_{op}}{\partial d_1} = K_1 b_1 - c_1$$

Solución 3.- En este caso las ecuaciones derivadas parciales dan lugar a las siguientes relaciones:

$K_1 Z_1 - L_1 = 0$

$K_2 Z_2 - L_2 = 0$

$-Z_1 + M_1 = 0$

$-Z_2 + M_2 = 0$

$K_1 X_1 - Y_1 - N_1 - N_3 = 0$

$K_2 X_2 - Y_2 - N_2 - N_3 = 0$

$b_1 - X_1 = 0$

$b_2 - X_2 = 0$

$Y_1 - c_1 = 0$

$Y_2 - c_2 = 0$

$d_1 - Z_1 = 0$

$d_2 - Z_2 = 0$

$\gamma - Z_1 - Z_2 = 0$

relacionándolas tenemos:

$L_1 = K_1 Z_1 \qquad X_1 = b_1$

$L_2 = K_2 Z_2 \qquad X_2 = b_2$

$M_1 = Z_1 \qquad Y_1 = c_1$

$M_2 = Z_2 \qquad Y_2 = c_2$

$N_1 = K_1 X_1 - Y_1 \qquad Z_1 = d_1$

$N_2 = K_2 X_2 - Y_2 \qquad Z_2 = d_2$

$N_3 = 0$

y podemos concluir que el valor residual máximo del terreno es:

$$V_{opt} = (K_1 b_1 - c_1)\, d_1 + (K_2 b_2 - c_2)\, d_2$$

Derivando parcialmente a Vopt. respecto a d_1 y d_2

$$\frac{\partial V_{op}}{\partial d_1} = K_1 b_1 - c_1$$

$$\frac{\partial V_{op}}{\partial d_2} = K_2 b_2 - c_2$$

De lo anterior podemos concluir que se pueden presentar tres casos con una solución diferente cada uno:

1.- Si $K_1 b_1 - c_1 > K_2 b_2 - c_2$

Hágase $Z_1 = d_1$ y determínese Z_2 de manera que se satisfagan la restricciones impuestas a Z_1 y Z_2

2.- Si $K_1 b_1 - c_1 = K_2 b_2 - c_2$

Hágase $Z_1 = d_1$ ó $Z_2 = d_2$ y determínese Z_2 ó Z_1 respectiva te, de manera que se satisfagan las restricciones impuestas a Z_1 y

3.- Si $K_1 b_1 - c_1 < K_2 b_2 - c_2$

Hágase $Z_2 = d_2$ y determínese Z_1 de manera que se satisfagan l restricciones impuestas a Z_1 y Z_2

Veamos por último, el caso de "N" utilizaciones factibles no excluyen-o visto con anteioridad, sugiere el siguiente procedimiento para determinar la zación de un terreno:

a).-Establecer las restricciones propias de cada utilización.

b).- Establecer las restricciones pertinentes para la utilización combina-eno. Estas relaciones, son del tipo $Z_1 + Z_2 \leq Y$ vistas anteriormente.

c).- Calcular los parámetros.

$N_1 = K_1 b_1 - c_1$

$N_2 = K_2 b_2 - c_2$

$\cdots\cdots\cdots$

$N_n \quad K_n b_n - c_n$

d).- Ordenar los valores anteriores en orden decreciente.

e).- Hacer $Z_I = d_I$ y determinar Z_{II} de manera que $Z_{II} = d_2$ ó que -an las restricciones de utilización combinada establecidas en b).-

f).- Determinados Z_I y Z_{II}, obtener Z_{III} de manera que $Z_{III} = d_{III}$ ó isfagan las restricciones de utilización combinada establecida en b).-

g).-Continuar con el procedimiento hasta ocupar el area de utilización-e.

Habiendo visto todos los casos que podrían presentarse en la aplicación-o de programación matemática a la determinación de la mejor utilización de un o nos queda más que hacer resaltar las ventajas de la aplicación de dicho pro-o:

I.-Es facil de aplicar.

II.-No requiere la elaboración de proyectos de utilización antes del aná-ndo el costo consecuente.

III.- Permite considerar tantas utilizaciones como se desee.

IV.- Permite obtener las características según las cuales debe desarrollarse el proyecto de utilización óptima.

5.- EJEMPLOS DE APLICACION PARA UN TERRENO SITUADO EN LA ZONA CENTRAL DE LA CIUDAD DE MEXICO.

Supongamos un terreno de 10 m. por 30 m., por lo tanto con un area

$$Ar = 300\ m^2$$

Vamos a suponer que se encuentra ubicado en la zona centro de la Ciudad, digamos en la calle de Gante entre las calles de Madero y 16 de Septiembre.

Proceso general.- Primeramente se haría un estudio comparativo del medio que rodea al terreno para ver que proyectos serían posibles de utilización del terreno, o sea según su ubicación. Sería absurdo pensar en un campo deportivo o en un cinematógrafo por el tamaño y la localización del terreno. Entonces se debe pensar en utilizaciones factibles. Para esto tenemos dos fuentes principales: el inversionista y el mercado de Bienes Raices.

Como segundo paso sería la obtención de los datos necesarios:

1.- Valor de la construcción "y"

2.- $\beta = \frac{Ar}{Ac}$

3.- $Z = \frac{Ac}{Ar}$

4.- Deducciones a la renta " α "

5.- Renta mensual bruta "x"

6.- Vida económica.

7.- Tasa de intereses sobre el capital "ic"

8.- Tasa de amortización "ia".

Todos estos datos los obtendríamos por el estudio del mercado de la construcción y del mercado de Bienes Raices, por sugestiones del inversionista y por consulta con los diferentes reglamentos constructivos.

El siguiente paso sería la aplicación de las diferentes fórmulas para cada utilización factible.

Y por último, se compararían los datos escogiendo el mejor de todos.

Utilizaciones factibles.-

I.- Departamentos

II.- Oficinas

III.- Hotel.

IV.- Estacionamiento

V.- Estacionamiento y anuncios comerciales

VI.- Comercio, departamentos y oficinas.

Vamos a agrupar las utilizaciones factibles excluyentes (I, II, III, IV) y considerar el máximo de altura permisible por la ubicación del terreno, según el regalmento de las construcciones del D. D. F.

Datos: 9 Plantas de construcción; $At = 9 \times 300 = 2{,}700\ m^2$.

UTILIZACION / CONCEPTO.	U_I	U_{II}	U_{III}	U_{IV}
Valor de la construcción "Y"	1500.00	1,100.00	1,200.00	700.00
$\beta = \frac{Ar}{Ac}$	0.90	0.90	0.80	0.95
$Z = \frac{Ac}{At}$	0.80	0.80	0.80	0.95
Deducciones a la renta "α"	0.30	0.20	0.40	0.05
Renta mensual "X"	30.00	30.00	40.00	15.00
Tasa de intereses "ic"	0.06	0.06	0.06	0.06
Tasa de amortización "ia"	0.03	0.02	0.03	0.01
Tasa de capitalización "ic + ia"	0.09	0.08	0.09	0.07

Resolución:

UTILIZACION / CONCEPTO	U_I	U_{II}	U_{III}	U_{IV}
$Ac = Z\ At$	2,160.00	2,160.00	2,160.00	2,565.00
$Ar = \beta\ Ac$	1,944.00	2,187.00	1,728.00	2,308.50
$K = \frac{12(1-\alpha)\beta}{ic + ia}$	84.11	108.00	64.00	155.74
KX	2,523.30	3,240.00	2,560.00	2,336.10
$KX - Y$	1,023.30	2,140.00	1,360.00	1,636.10
$V=(KX-Y)\ Z$	818.64	1,712.00	1,088.00	1,554.30

La utilización V sería aprovechar el terreno al nivel del piso como estacionamiento y usar todo el frente, con la construcción de una estructura, para anuncios. La inversión sería muy pequeña, así como la construcción. El valor residual del terreno, sería la suma del valor residual de cada una de las utilizaciones excluyentes.

Datos:

$$U_V \text{ - - - - - - } \left\{ \begin{array}{ll} U_{V_a} & \text{Estacionamiento.} \\ U_{V_b} & \text{Anuncios comerciales.} \end{array} \right.$$

UTILIZACION / CONCEPTO	U_{V_a}	U_{V_b}
Valor de la construcción "Y"	50.00	100.00

$\beta = \frac{Ar}{Ac}$	1.00	1.00
$Z = \frac{Ac}{At}$	0.95	0.95
Deducciones a la renta "α"	0.10	0.40
Renta mensual "X"	10.00	20.00
Tasa de intereses "ic"	0.06	0.06
Tasa de amortización "ia"	0.03	0.06
Tasa de capitalización "ic+ia"	0.09	0.12

Resolución:;

UTILIZACION / CONCEPTO	U_{V_a}	U_{V_b}
$Ac = Z At$	275.00	256.50
$Ar = \beta Ac$	275.00	256.50
$K = \frac{12(1-\alpha)\beta}{ic + ia}$	120.00	60.00
KX	1,200.00	1,200.00
KX - Y	1,150.00	1,100.00
V = (KX-Y)Z	1,092.50	1,045.00

Por lo tanto $V_V = 1,092.50 + 1,045.00 = 2,137.50$

Utilización U_{VI} .- U_{VI_a} : Comercio : 540.00 m^2

U_{VI_b} : Departamentos : 810.00 m^2

U_{VI_c} : Oficinas : 1,080.00 m^2

$At = 9 \times 300 = 2,700.00$ m^2

Datos y restricciones propias de cada utilización:

UTILIZACION / CONCEPTO	U_{VI_a}	U_{VI_b}	U_{VI_c}
Valor de la construcción "Y" = c	900.00	1,500.00	1,100.00
$\beta = \frac{Ar}{Ac}$	0.80	0.90	0.90
$Z = \frac{Ac}{At} = d$	$\frac{540.00}{2,700.00} = 0.20$	$\frac{810}{2,700.00} = 0.30$	$\frac{1080}{2700} = 0.40$
Deducciones a la renta "α"	0.40	0.30	0.20
Renta mensual "X = b"	40.00	30.00	30.00
Tasa de intereses "ic"	0.06	0.06	0.06
Tasa de amortización "ia"	0.03	0.03	0.03
Tasa de capitalización "ic + ia"	0.09	0.09	0.09

Utilización combinada del terreno:

$$\gamma \geq z_1 + z_2 + z_3 = 0.20 + 0.30 + 0.40 = 0.90$$

Cálculo de parámetros:

UTILIZACION / CONCEPTO	U_{VI_a}	U_{VI_b}	U_{VI_c}
$K = \frac{12(1-\alpha)\beta}{ic + ia}$	64.00	84.00	96.00
Kb	2,560.00	2,520.00	2,880.00
Kb - c = N	1,660.00	1,020.00	1,780.00
V = Nd	332.00	306.00	712.00

Cálculo del valor residual del terreno:

$$V_{VI} = V_{VI_a} + V_{VI_b} + V_{VI_c} = 332.00 + 306.00 + 712.00 = 1,350.00$$

En este tipo de construcción de número de plantas, un problema interesante que se presenta, es saber que cantidad de plantas nos dá el óptimo valor residual del terreno. En nuestro caso de 9 plantas, vamos a estudiar este caso llamando U_1, U_2.... U_9 según tengamos 1,2,....9 plantas. De las utilizaciones excluyentes vistas en un principio, observamos que el valor residual máximo se obtiene para aquella utilización en la cual dedicamos todo el edificio a oficinas. Para el caso, llamémoslo "de plantas", que vamos a analizar, vamos a pensar que todos estarán dedicados a oficinas.

Datos:

CONCEPTO	UTILIZACION U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8
Valor de la construcción "Y"	800	800	825	850	900	900	1000	1050
$\beta = \frac{Ar}{Ac}$	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
$Z = \frac{Ac}{At}$	0.95	0.90	0.90	0.85	0.85	0.85	0.80	0.80
Deducciones a la renta "α"	0.20	0.15	0.20	0.20	0.20	0.20	0.20	0.20
Renta mensual "X"	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Tasa de intereses "ic"	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Tasa de amortización "ia"	0.01	0.01	0.015	0.015	0.015	0.02	0.02	0.02
Tasa de capitalización "ic+ia"	0.07	0.07	0.075	0.075	0.075	0.08	0.08	0.08

Resolución:

CONCEPTO	UTILIZACION U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8
$Ac = ZAt$	285.00	540.00	810.00	1020.00	1275.00	1530.00	1680.00	1920.00
$Ar = \beta Ac$	256.50	486.00	729.00	918.00	1147.50	1377.00	1512.00	1728.00
$K \frac{12(1-\alpha)\beta}{ic + ia}$	123.43	131.14	115.20	115.20	115.20	108.00	108.00	108.00
KX	3702.90	3934.20	3456.00	3456.00	3240.00	3240.00	3240.00	3240.00
$KX - Y$	2902.90	3134.20	2631.00	2606.00	2556.00	2340.00	2240.00	2190.00
$V \ (KX-Y) \ Z$	2757.76	2820.78	2367.90	2215.10	2172.60	1989.00	1792.00	1752.00

Todavía, podemos seguir analizando el caso "de plantas":

Según el Reglamento de las Construcciones del D.D.F., el terreno de nuestro ejemplo, tiene un límite permisible de nueve plantas. Sin embargo, por medio de hacer la construcción escalonada podemos seguir aumentando plantas sin salirnos de la restricción. Vamos a ver este caso:

Sea una reducción en la planta, a la altura nueve, de 10 m. por 20 m.- El reglamento nos permite aumentar nueve plantas mas.

Datos:

CONCEPTO	UTILIZACION U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}	U_{17}	U_{18}
Valor de const. "Y"	1150	1200	1225	1250	1300	1400	1500	1700	1900
$\beta = \frac{Ar}{Ac}$	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
$Z = \frac{Ac}{At}$	0.80	0.80	0.75	0.75	0.75	0.70	0.70	0.70	0.70
Deduc. a la renta "α"	0.20	0.22	0.22	0.25	0.25	0.30	0.30	0.35	0.35
Renta mensual "X"	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Tasa de intereses "ic"	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Tasa de amortiz. "ia"	0.02	0.025	0.025	0.03	0.03	0.04	0.04	0.05	0.06
Tasa de capit. "ic+ia"	0.08	0.085	0.085	0.09	0.09	0.10	0.10	0.11	0.12

Resolución:

UTILIZACION / CONCEPTO	U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}	U_{17}	U_{18}
$Ac = ZAt$	2320.00	2480.00	2475.00	2625.00	2775.00	2730.00	2870.00	3010.00	3150.00
$Ar = \beta Ac$	2088.00	2232.00	2227.50	2362.50	2497.50	2457.00	2583.00	2709.00	2835.00
$K = \frac{12(1-\alpha)\beta}{ic + io}$	108.00	99.11	99.11	90.00	90.00	75.60	75.60	63.82	58.50
KX	3240.00	2973.30	2973.30	2700.00	2700.00	2268.00	2268.00	1914.60	1755.00
$KX - Y$	2090.00	1773.30	1748.30	1450.00	1400.00	868.00	768.00	214.60	-145.00
$V\ (KX-Y)\ Z$	1672.00	1418.64	1311.23	1087.50	1050.00	607.60	537.60	150.22	-101.50

Podemos decir, de la observación de todos los valores residuales del terreno obtenidos, que la mejor utilización del terreno de nuestro ejemplo, es aquella en la que construyamos un edificio de dos plantas y lo dediquemos a oficinas.

6.- CONCLUSIONES.

Como hemos visto en el capítulo precedente, la aplicación de la programación matemática a la obtención de la mejor utilización de un terreno es fácil y por esta razón permite una gran combinación de utilizaciones, con una inversión de tiempo relativamente baja. La obtención de los datos necesarios es tambien fácil y rápida.

Vimos tambien, en el ejemplo "de plantas", que llega un momento; conforme vamos aumentando plantas; en que el valor de la construcción, las deducciones a la renta y la tasa de amortización se hacen muy altas y no podemos incrementar la renta, ni el factor de utilización del terreno, por estar en sus límites respectivos, de esta forma obtenemos valores residuales del terreno negativos.

O sea, que desde el punto de vista de inversión,no conviene construir tal número de plantas.

Desde el mismo punto de vista y como una consecuencia de lo anterior,si los valores residuales del terreno obtenidos en las diferentes utilizaciones analizadas nos dieran valores inferiores a lo que ese mismo terreno sin construir vale en el mercado de Bienes Raices, no nos convendría ninguna construcción, sino mas bien vender el terreno a su valor actual según el mercado.

En resumen, la aplicación del método propuesto para determinar la mejor utilización de un terreno, nos permite un dominio fácil, rápido y completo del problema y una gran intimidad con los deseos del inversionista.

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6. BOP AN APPROACH TO BUILDING OPTIMIZATION

Proceedings of the Association
of Computing

Machinery, 1968.

6

BOP—An approach to building optimization

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INTRODUCTION

The problem of finding an appropriate building configuration to satisfy a client's building program is by no means rudimentary. When one imposes additional requirements that the building shall be an "efficient", "economical", or "optimum cost" building, the mathematical difficulties encountered in operating on a large data base to achieve some kind of optimum result are almost insurmountable.

In the past, these formidable problems of searching out the best—or even an acceptable—solution have been solved largely on the basis of intuition and random investigation of a small number of possible solutions. The numerous successful buildings in our cities today are a testimony to man's remarkable and innate ability to intuit, evaluate, and synthesize. It is conceivable, however, that these as yet unexplained human abilities can be extended and magnified if proper use could be made of appropriate computer techniques dealing with information processing.

STATEMENT OF THE PROBLEM

By and large, most approaches to computer implementation in building design in the past have been very fragmented and narrowly limited in scope. Although there have been forceful historical reasons for these limitations, this mode of computer usage is nevertheless remarkable when one considers that the basic nature of building design is the exact opposite of fragmentary and limited in scope. As Teague and others have pointed out, the true nature of architecture and engineering encompasses the synthesized whole of the project, and not simply isolated disciplines.[1] Only recently, however, have there been developments in computer technology—notably problem-oriented languages and certain internal data structuring techniques—that offer promise of allowing the designer to grasp the systematic whole of the problem.

The general mathematical problem of optimization is simply stated as the problem of finding an extreme value (minimum or maximum) of some objective function (such as cost), subject to some set of constraints. The techniques for solving the problem have often been quite elegant, and are well documented throughout the literature. See, for example, Reference 2 for a bibliography of works in the general area of linear programming.)

The practical problem of building design can be formulated, in a general way, as an optimization problem. The objective could be minimum initial cost, life-time cost, operating cost, maximum return on investment, etc. This objective is, of course, subject to a variety of constraints due to client program, site limitations, space allocation, design considerations, code constraints, environmental factors, engineering requirements, financing, etc. Hence the practical problem of finding an "optimum" building is in some ways quite similar to the classical problem of mathematical optimization.

Historically, however, mathematical optimization techniques within the design professions have been applied to only a very limited scope of the design problem. Witness, for example, typical optimization applications in minimum cost for the three-bar truss problem,[3] minimum structural steel weight,[4] minimum time or travel distance in transportation planning, maximum space utilization, etc. When the scope of the project is broadened from finding the minimum weight of structural steel in a building frame to finding that combination of parameters which give the minimum cost for the total building, including window wall, elevators, structural, mechanical, electrical, etc., one sees immediately the implication that such a scope has on the solution techniques.

AN APPROACH TO OPTIMIZATION

Inasmuch as real buildings are composed of more than a single isolated discipline, it is absolutely imperative that any meaningful approach to optimization must treat the total problem, however crudely, rather than spend elaborate methods on some isolated part of the problem. That this total approach is a sine qua non is obvious from the observation that the optimization of an isolated discipline can and frequently does result in considerable distortion of the total optimization objective.

This philosophy, viz., that building optimization must treat the total building complex if it is to be meaningful, forms the basis of the approach discussed herein. As mentioned earlier, the scope of such a problem necessarily dictates that the initial solution techniques be rather crude. As a matter of fact, the BOP programs described below are only in a very general sense "optimization" routines. No direct use is made of linear or non-linear programming or of any of the more sophisticated techniques in game theory, etc. Perhaps as experience is gained concerning the way a total building project behaves under permutation of some of the critical parameters, the classicial techniques of mathematical optimization can lead to a more refined treatment of the controlling parameters for the complete problem.

BOP—A BUILDING OPTIMIZATION PROGRAM

A series of modular programs for optimizing the configuration of high-rise office buildings has been developed recently to test the total systems approach described above. These Building Optimization Programs (BOP) have been developed using the Problem Language Analyzer[5] (PLAN), which was developed by Sams, et. al. The BOP system is operational on a standard 8K IBM 1130, with disk, card reader, and line printer.

In order to organize the large amount of information inherent in a total building design, four major subsystems are identified as the dominant cost influencing elements of the building:

1. Window Wall
2. Elevatoring
3. Heating, Ventilating, and Air Conditioning (HVAC)
4. Structural

Obviously, each of these four subsystems depends upon a common data base of geometry, environmental data, and design limits. A fifth subsystem, which includes all remaining cost items in the building, can also be included for completeness, although it is the four subsystems listed above that are given most intensive treatment as the dominant cost factors.

A basic concept in BOP is that the designer can specify to the computer as little or as much as he likes about his project. BOP will then supply reasonable values for missing data by default, and proceed to formulate complete, albeit crude, internal models of the building project. (The importance of this concept of a complete internal model of the project is well documented in the publication by Krauss and Myer.[6]) These models are then tested against site limitations, client specifications, architectural design constraints, and code requirements. (All of these limits are, of course, variable at the problem-oriented language level by the designer.) If the internal geometrical model of the total building passes all these tests, computations of varying complexity are done for the window wall, elevatoring, mechanical, and structural subsystems, all of which are based on a common internal data base. The costs of these subsystems are then evaluated, along with costs for the agglomerate fifth subsystem, and the total solution stored on disk. If the various constraints are loose enough, additional geometrical solutions are generated, tested, and evaluated. In addition to keeping all valid solutions for possible development in the future, a set of pointers is kept for those solutions which gave the least total cost, least square-foot cost, and maximum return on investment.

Strictly speaking, the procedure outlined above is not optimization in the classical mathematical sense of the word. In a more general sense, however, the procedure is of an optimizational nature, insofar as it delineates the permissible solution space, generates and evaluates solutions within that space. Inasmuch as all possible solutions in the solution space are evaluated, the actual "optimization procedure" is basically a "brute force" method. This is not as inefficient as it may appear at first glance, since restrictions on the design space frequently limit the solution space to only a few individual solutions. Also, the output from all admissible solutions which the procedures generate is frequently of direct use in the design process, regardless of its position in the search path for the optimum solution.

To illustrate briefly the nature of the programs and available commands,* suppose that early discussion with a client has indicated a need for a gross area of about 300,000 square feet, with about 14,000 to 16,000 square feet per floor. The site is in the center of the city, and has dimensions of 125 feet by 150 feet. The following BOP commands might be used to describe this information.

```
JOB NAME, 'CLIENT X';
BUILDING OPTIMIZATION PROGRAM;
TARGET GROSS AREA, 300000;
FLOOR AREA LIMITS,
```

---

*A complete list of BOP Vocabulary is given in Appendix A.

MINIMUM 14000 MAXIMUM 16000;
BUILDING LENGTH LIMITS, MAXIMUM 150;
BUILDING WIDTH LIMITS, MAXIMUM 125;

It is important to note that in these early stages of the building project, only the barest information is available. It is, therefore, necessary to have a powerful default feature which assumes reasonable, consistent values for all data not explicitly given. The second statement, "BUILDING OPTIMIZATION PROGRAM," actually links to a series of programs which does a complete initialization of various geometry, cost, and subsystem files internally. Thus complete and sufficient information is available immediately after execution of this second command to generate a wide range of possible solutions. Any additional descriptive information such as that given above replaces the originally assumed data, and therefore begins to shape the internal solutions more closely to the specific project at hand. If, as is frequently the case, the information given above is all that is known initially, the designer can issue the command

BLOCK OUT GEOMETRY;

This command links successively to a series of programs for generating geometry to fit within the assumed or prescribed limits, test that geometry for acceptability, and perform various computations and cost calculations for the four subsystems mentioned previously. The last program in the link prints a summary report of the internal design limits as they currently exist, and the solution geometries which were found to fit within these limits (Figure 1). The overall cost of each solution is also printed.

```
JOB TITLE CLIENT X
ALL SOLUTIONS AT 1 FLOOR INCREMENTS

DESIGN LIMITS                    MINIMUM     MAXIMUM      TARGET
GROSS FLOOR AREA                 270000.     330000.     300000.
GROSS AREA PER FLOOR              14000.      16000.
BUILDING WIDTH                    50.000     125.000
BUILDING LENGTH                   50.000     150.000
CORE WIDTH                        25.000     250.000
CORE LENGTH                       25.000     250.000
CORE TO EXTERIOR SPAN             35.000      45.000
NUMBER OF STORIES                      1         100
LENGTH WIDTH RATIO                 1.000       2.000
SHAPE INCREMENT                    0.200
NUMBER OF SOLUTIONS                               25
GLASS LINE OFFSET                                          0.000
BLDG LINE OFFSET                                           0.000
MODULE CHOICES      5- 0

ID FL  MODL  LEASE  -FLOOR DIMENSIONS-  -CORE DIMENSIONS--  GROSS   TOTAL   TOTAL  TOTAL  BLDG   UNIT  RETURN
NO NO         SPAN  L  W LENGTH  WIDTH  L  W LENGTH  WIDTH PER FL   GROSS    RENT    PCT  COST   COST    ON
      FT IN  FT IN         FT IN  FT IN        FT IN  FT IN  SQ FT   SQ FT   SQ FT   RENT $1000  $/SF  INVEST


 1 18  5- 0  35- 0 25 25 125- 0 125- 0  8 11  40- 0  55- 0  15625. 281250. 240862.  85.6  7385. 26.25   9.85
 2 18  5- 0  35- 0 29 21 145- 0 105- 0 13  7  65- 0  35- 0  15225. 274050. 234194.  85.4  7273. 26.54   9.39


 3 19  5- 0  35- 0 25 25 125- 0 125- 0  8 11  40- 0  55- 0  15625. 296875. 255649.  86.1  7730. 26.04  10.34
 4 19  5- 0  35- 0 26 22 130- 0 110- 0 11  8  55- 0  40- 0  14300. 271700. 232236.  85.4  7250. 26.68   9.21
 5 19  5- 0  35- 0 29 21 145- 0 105- 0 13  7  65- 0  35- 0  15225. 289275. 248581.  85.9  7612. 26.31   9.89


 6 20  5- 0  35- 0 25 25 125- 0 125- 0  8 11  40- 0  55- 0  15625. 312500. 269488.  86.2  8068. 25.81  10.70
 7 20  5- 0  35- 0 24 24 120- 0 120- 0  9 10  45- 0  50- 0  14400. 288000. 246617.  85.6  7605. 26.40   9.64
 8 20  5- 0  35- 0 26 22 130- 0 110- 0 11  8  55- 0  40- 0  14300. 286000. 244750.  85.5  7563. 26.44   9.57
 9 20  5- 0  35- 0 29 21 145- 0 105- 0 13  7  65- 0  35- 0  15225. 304500. 262020.  86.0  7944. 26.08  10.24


10 21  5- 0  35- 0 24 24 120- 0 120- 0  9 10  45- 0  50- 0  14400. 302400. 258933.  85.6  8012. 26.49   9.52
11 21  5- 0  35- 0 26 22 130- 0 110- 0 12  8  60- 0  40- 0  14300. 300300. 256966.  85.5  7981. 26.57   9.39
12 21  5- 0  35- 0 29 21 145- 0 105- 0 13  7  65- 0  35- 0  15225. 319725. 275161.  86.0  8368. 26.17  10.14


13 22  5- 0  35- 0 24 24 120- 0 120- 0  9 10  45- 0  50- 0  14400. 316800. 272390.  85.9  8354. 26.37   9.84
14 22  5- 0  35- 0 26 22 130- 0 110- 0 12  8  60- 0  40- 0  14300. 314600. 270323.  85.9  8320. 26.44   9.71

          OPTIMUM SOLUTIONS

             LEAST COST                     SOLUTION  4
             LLAST $/SF                     SOLUTION  6
             MAXIMUM RETURN ON INVESTMENT   SOLUTION  6
```

Figure 1—Overall Summary of Computer-Generated Solutions

Upon inspection of these solutions, the designer may choose several of them for further development. He would normally request additional details for a solution by commands such as

PRINT ARCHITECTURAL SUMMARY,
SOLUTION 3;
PRINT ENGINEERING SUMMARY,
SOLUTION 3;
PRINT COST SUMMARY, SOLUTION 3;

These commands link to BOP programs that produce the output shown in Figures 2, 3, and 4. Note that complete summaries of the architectural, engineering, cost and financial analyses are given for the requested solution number. Included in these summaries, of course, are details of the window wall, elevatoring, HVAC, and structural subsystems.

Each of the cost categories shown in Figure 4 has actually been aggregated as a sum of several smaller, component item costs. These items furnish a preliminary cost budget by trades, and can be retrieved directly by means of the command

PRINT COST BUDGET, SOLUTION 3;

Partial output from such a command is shown in Figure 5. A more complete description of the assumptions behind these cost items is contained in Appendix B.

Having obtained a set of solutions for the design parameters currently under investigation, the user can save the results for later use by issuing the command

SAVE BOP JOB, FILE 121;

This saves all problem data and solutions in a permanent users area file. Upon returning to the computer at a later date, the user can restore primary memory and certain working storage files to the identical state which existed when he left the machine by means of the command

RESTORE BOP JOB, FILE 121;

A limited number of files in the user area of disk have been reserved so that several jobs can be maintained at one time.

After reviewing the information produced at the first session with the computer, the designer might wish to restore several selected solutions, and to begin refining the elevator computations, cost assumptions, structural and mechanical systems, etc. Commands such as the following are typical of those available to him for this purpose.

RESTORE BOP JOB, FILE 121;
ELEVATOR ZONE DATA,
ZONE 1 ZPOP 1000;
SELECT ELEVATORS, ZONE 1;

```
                                        SOLUTION  3 ARCHITECTURAL SUMMARY
                                        ---------------------------------
                                        CLIENT X
PLAN DIMENSIONS
---------------
MODULE            5 FT  0 IN    LEASE SPAN    35 FT  0 IN
FLOOR LENGTH    125 FT  0 IN    CORE LENGTH   40 FT  0 IN
FLOOR WIDTH     125 FT  0 IN    CORE WIDTH    55 FT  0 IN
TRAVEL DISTANCE       77. FT


ELEVATION DIMENSIONS
--------------------
FIRST FLOOR           AT 20.00 FT =  20.00       TYPICAL STRUCTURAL DEPTH        21.0 IN  MECH. ROOM LOCATIONS
SECOND FLOOR          AT 12.50 FT =  12.50       TYPICAL MECHANICAL CLEARANCE    18.0 IN     FIRST    AT 19 FL
16 TYPICAL FLOORS     AT 12.50 FT = 200.00       TYPICAL LIGHTING CLEARANCE       6.0 IN     SECOND   AT*** FL
 1 MECHANICAL FLOORS  AT 20.00 FT =  20.00       TYPICAL FLOOR TO CEILING     8 FT  9 IN     THIRD    AT*** FL
   TOTALS             19 STORIES     252.50 FEET TYPICAL FLOOR TO FLOOR      12 FT  6 IN     PARTIAL  AT*** FL


TYPICAL FLOOR AREAS (SQ. FT.)
-----------------------------
GROSS PER FLOOR         15625.   MECHANICAL  315. FIRE TOWER   0. NO. TOILET FIXTURES   5
TOTAL BLDG GROSS       296875.   STAIRS      280. TELEPHONE   43. STAIR WIDTH REQD.    88. IN.
TOTAL BLDG RENTABLE    255649.   JANITORS CL  15. TOILET     357.
OVERALL EFFICIENCY        86.1   ELECTRIC CL  80. PART MECH    0.


ELEVATOR ZONING AND PERFORMANCE
-------------------------------
ZONE LOW   HIGH ZONE   ZONE   LOCAL TOTAL  CAB   CAB  INTERVAL CAPACITY CAPACITY SHAFT  LOBBY  TOTAL FLOOR
    FLOOR FLOOR  POP  DENSITY CARS  CARS  SIZE  SPEED SECONDS   PCT     PEOPLE   AREA   AREA   CORE  EFF
 1    2    10   909.   125.    4.    9.  3000.  500.   29.9     17.6     160.    720.   450.  2261.  91.5
 2   11    18   808.   125.    5.    5.  3000.  700.   25.6     23.1     187.    400.   250.  1761.  93.6

 0. FREIGHT ELEVATORS
```

Figure 2—Architectural Summary

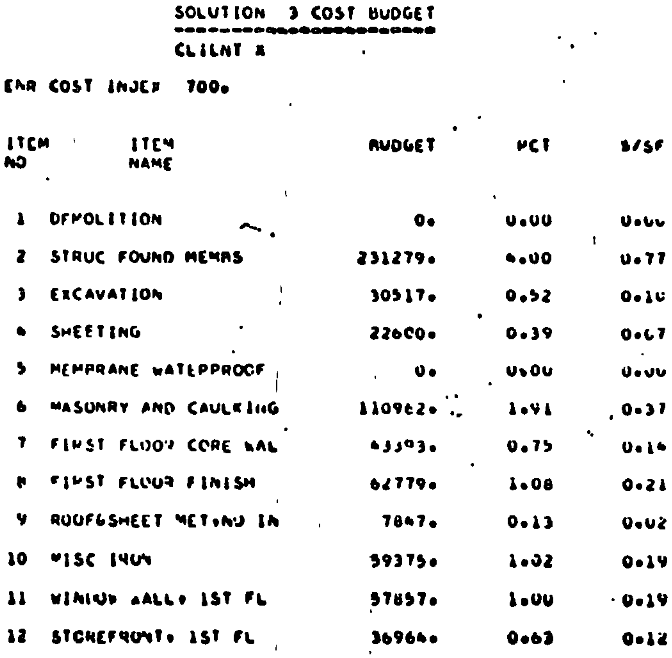
```
                                     SOLUTION  3 ENGINEERING SUMMARY
                                     -------------------------------
                                     CLIENT X
STRUCTURAL
----------
FLOOR SPAN     35.0 FT  BASE COST                 3.50 SPAN PREMIUM     0.30     FOR SPANS   20. TO  40. FEET
UNDERFLOOR DUCT         UNDERFLOOR DUCT PREMIUM 0.50 HEIGHT PREMIUM   1.00     FOR HEIGHTS 20. TO  60. STORIES
PERIMETER AIR           PERIMETER AIR PREMIUM    0.15
EXPOSED STRUCTURE       EXPOSURE PREMIUM          0.30
                                                     STRUCTURAL COST 1150390. =  3.87 / SQFT

HVAC
----
                        WINDOW WALL CHARACTERISTICS  ENVIRONMENTAL DATA        ILLUMINATION          3.50 WATTS
COST MULTIPLIER   1.00    PCT GLASS     60.00          TEMP. INSIDE   75.00 CONVENIENCE OUTLETS 0.50 WATTS
COST PER TON   1200.00    BLINDS FACTOR  0.56          TEMP. OUTSIDE  95.00 BLDG POPULATION  2250.00 PEOPLE
PERIM ZONE DEPTH 15.00    UGLASS         1.13          SOLAR GAIN    126.00 GROSS SPACE REQ     0.050*GROSS
                          UWALL          0.25          OUTSIDE AIR     0.20
                                                       BTU/CFM        47.00

PERIMETER ZONE 118800. SQFT      BTU    8107355.              COST          810735.
INTERIOR  ZONE 133078. SQFT      BTU    3546281.              COST          354628.
       TOTALS 251878. SQFT      BTU   11653636.            TOTAL COST     1165363. =  3.92 / SQFT
```

Figure 3—Engineering Summary

```
                                 SOLUTION  3 COST AND FINANCIAL SUMMARY
                                 --------------------------------------
                                 CLIENT X

ENR COST INDEX  700.

BUILDING                        TOTAL     0/0      $/SF

    SITE WORK                 $       0.   0.00    $  0.00

    FOUNDATION                $  285151.   4.93    $  0.96

    SUPERSTRUCTURE            $ 1150390.  19.89    $  3.87

    EXTERIOR WALL             $  977691.  16.90    $  3.29

    ARCHITECTURAL FINISHES $  611833.  10.58    $  2.06

    ELEVATORS                 $  531160.   9.18    $  1.78

    PLUMBING                  $  296874.   5.13    $  0.99

    HVAC                      $ 1165363.  20.15    $  3.92

    ELECTRICAL                $  231279.   4.00    $  0.77

    GENERAL CONDITIONS        $  387704.   6.70    $  1.30

    G. C. FEE                 $  144549.   2.49    $  0.48
                                ---------  ----      ------
BASE BUILDING COST -------- $ 5781995. 100.00    $ 19.47

    CONTINGENCY               $  576199.   9.99    $  1.94

    TENANT                    $ 1283961.  22.20    $  4.32

    EQUIPMENT, FURNITURE      $   86729.   1.49    $  0.29

    OTHER                     $       0.   0.00    $  0.00
                                *********           *******
OVERALL BUILDING COST ------$ 7730885. 133.70    $ 26.04
                                *********           *******

OVERALL DIMENSIONS     19 STORIES           LENGTH   125.00   WIDTH  125.0   HEIGHT  252.5   LSPAN 35.0   MODULE 5.00
TOTAL BUILDING AREA          GROSS  296875.   RENTAL  255649.
AREA PER RENTABLE FLOOR      GROSS   15625.   RENTAL   14202.

RENTAL RATE       ($/SQFT)    6.00             LAND COST               773088.
OPERATING EXPENSES (PCT)   40.00             TOTAL PROJECT COST  9416216.
VACANCY RATE        (PCT)     5.00             MORTGAGE AMOUNT       7062161.
MORTGAGE AVAILABLE (PCT)   75.00             EQUITY                  2354054.
DEBT SERVICE        (PCT)     8.50             GROSS INCOME          1533897.
LEGAL, FINANCING + PREM       5.00             NET INCOME              243359.
A-E FEE             (PCT)     6.00             RETURN ON INVESTMENT     10.34
```

Figure 4—Cost and Financial Summary

ENTER COST DATA, ITEM { DOLLARS_____ PCT_____ SQ FT _____ UNIT PRICE_____ };
ENVIRONMENTAL DATA, TEMPERATURE INSIDE_____ OUTSIDE_____;
STRUCTURAL SPAN, MINIMUM_____ MAXIMUM_____;
COMPUTE COSTS, SOLUTION 3;
COMPUTE RETURN ON INVESTMENT, SOLUTION_____;



```
              SOLUTION  3 COST BUDGET
              -----------------------
              CLIENT X

ENR COST INDEX  700.

ITEM       ITEM                        BUDGET       PCT      $/SF
NO         NAME

  1  DEMOLITION                            0.      0.00      0.00
  2  STRUC FOUND MEMBS                231279.      4.00      0.77
  3  EXCAVATION                        30517.      0.52      0.10
  4  SHEETING                          22600.      0.39      0.07
  5  MEMBRANE WATERPROOF                   0.      0.00      0.00
  6  MASONRY AND CAULKING             110962.      1.91      0.37
  7  FIRST FLOOR CORE WAL              43393.      0.75      0.14
  8  FIRST FLOOR FINISH                62779.      1.08      0.21
  9  ROOF&SHEET MET,NO IN               7847.      0.13      0.02
 10  MISC IRON                         59375.      1.02      0.19
 11  WINDOW WALL, 1ST FL               57857.      1.00      0.19
 12  STOREFRONT, 1ST FL                36964.      0.63      0.12
```

Figure 5—Portion of Cost Budget

By this time, the designer is well into his design, and the problem is one of further refinement of a set of selected solutions. The important point to remember, however, is that these selected solutions have come from systematic investigation of all geometries which fell within given limitations, and that the solution costs of the valid solutions were generated on the basis of the total project, not just a single component of the project. Although the so-called "optimum" solutions so found may not be chosen for further development, the designer at least knows what premium is involved in making this decision.

SUMMARY AND CONCLUSION

An approach to building optimization has been presented which emphasizes the totality of the building project in the optimization effort. Some discussion of the nature of the necessary information base and the language for manipulating it has been presented. A few commands from the BOP language and some typical output are given to illustrate the nature of the man/machine communication and the scope and depth of treatment of the currently existing capabilities.

ACKNOWLEDGMENT

The work presented here was initiated at Skidmore, Owings & Merrill. The early collaboration of C. David Sides, consultant, is hereby acknowledged. The program is under continual development at SOM, and is under the general direction of B. J. Graham, partner. Significant contributions have also been made by R. Diamant, R. Lenke, S. Sachs, and F. Khan.

APPENDIX A. VOCABULARY FOR BUILDING OPTIMIZATION

JOB NAME, '__________';
BUILDING OPTIMZATION PROGRAM;
TARGET GROSS AREA,_______;
GROSS AREA LIMITS, MINIMUM_______, MAXIMUM_______;
FLOOR AREA LIMITS, MINIMUM_______, MAXIMUM_______;
NUMBER OF STORIES, MINIMUM_______, MAXIMUM_______;
BUILDING LENGTH LIMITS, MINIMUM ____, MAXIMUM_______;
BUILDING WIDTH LIMITS, MINIMUM_______, MAXIMUM_______;
LENGTH WIDTH RATIO, MINIMUM_______, MAXIMUM_____, INCREMENT_____;
CORE LENGTH LIMITS, MINIMUM_______, MAXIMUM_______;
CORE WIDTH LIMITS, MINIMUM_______, MAXIMUM_______;
LEASE SPAN LIMITS, MINIMUM_______, MAXIMUM_______;
MAXIMUM NUMBER OF SOLUTIONS,_______;
STORY HEIGHTS, FIRST_____, SECOND_____, TYPICAL_____, MECHANICAL_____;
INVESTMENT DATA, RENT_____, OPERATING EXPENSES_____, PCT, VACANCY_____, MORTGAGE_____, DEBT SERVICE_____, LAND COST_____, AE FEE_____, PROMOTION_____;
ADD MODULE,_____FEET_______ INCHES;

```
COMPUTE RETURN ON INVESTMENT,

    SOLUTION { ________TO ________ };
                       ALL
DELETE MODULE,______ FEET______INCHES;
NUMBER OF FREIGHT ELEVATORS,______;
BLOCK OUT GEOMETRY, EVERY____FLOORS;
CODE CONSTANTS, BPOP______, PFIN______,
    PNET______, HFIRE______, TRAVL______;
ELEVATOR ZONE DIVISIONS,________ BANK
    FROM________TO________ STORIES DIVIDE
    ____________;
MECHANICAL SPACE REQUIREMENTS, OVER-
    ALL______ PER FLOOR ______,
ELEVATOR ZONE DATA, ZONE______, LOW
    __________, HIGH______, EXPRESS______;
    ZDENS______, ZPOP______, FLOOR AREA
    __________;
CAB DATA, ZONE______, SIZE______, SPEED
    __________, DTIME______, DWID______,
    KEY______;
ELEVATOR CRITERIA, ZONE______, INTER-
    VAL______, CAPACITY______;

SELECT ELEVATORS, ZONE ______;
WINDOW WALL CHARACTERISTICS, PCT GLASS
    __________, UGLASS______, UWALL______,
    BLINDS FACTOR ______;
ENVIRONMENTAL DATA, AIR INTAKE BTU
    __________, TEMPERATURE INSIDE______,
    TEMPERATURE OUTSIDE ______, SOLAR
    GAIN______;

ELECTRICAL DATA, ILLUMINATION ________
    CONVENIENCE OUTLETS________WATTS;
MECHANICAL PERIMETER ZONE, MINIMUM
    ________ FT, MAXIMUM________FT;
MECHANICAL SYSTEM TYPE, INDUCTION,
    COST FACTOR______, CLEARANCE______;
ENR COST INDEX, ______;
STRUCTURAL SPAN, MINIMUM________,
    MAXIMUM ______;

PRINT COST ASSUMPTIONS;

ENTER COST DATA, ITEM ______
             { DOLLARS ______________ }
             { PCT___________________ }
             { SQ FT_________________ }
             {   UNIT PRICE__________ }

PRINT ARCHITECTURAL SUMMARY,

              SOLUTIONS { ___TO___ }
                            ALL

PRINT ENGINEERING SUMMARY,

              SOLUTIONS { ___TO___ }
                            ALL

PRINT COST SUMMARY,

              SOLUTIONS { ___TO___ }
                            ALL

PRINT COST BUDGET,

              SOLUTIONS { ___TO___ }
                            ALL

SAVE BOP JOB, FILE ______;
RESTORE BOP JOB, FILE______;
SAVE DATA, FILE ______;
RESTORE DATA, FILE______;
PRINT BOP JOB LIST;
```

APPENDIX B. BASIS FOR BOP COST COMPUTATIONS

Although the building costs are by no means the only useful result from BOP, they are sufficiently important to warrant a somewhat fuller explanation of the assumptions behind the cost summaries and budgets mentioned in the text. A single command is available to give a complete listing of unit costs and assumed quantities:

```
PRINT COST ASSUMPTIONS;
```

Upon recognition of this command, the BOP routines produce output of the nature shown in Figure 6.

A few words of explanation should be sufficient to enable the reader to grasp the essence of the cost approach implied by Figure 6. In general, the cost of each of 50 component items is given in one of four ways:

1. As an absolute dollar amount, column 1.
2. As a percentage of the base building cost, column 2.
3. As a dollars per square foot of gross building, column 3.
4. In some "other" rational way—generally as a unit price times a quantity which is a function of the building geometry.

```
                                        LIST OF COST ASSUMPTIONS   - BY ITEMS
ITEM        ITEM                DOLLARS     PCT  $/SQ FT          ITEM COMPONENTS                          ACTION   IF
NO          NAME                                                                                           ASSUMED VALUE = 0

  1  DEMOLITION                      0.  ******  *******                                  ********

  2  STRUCT FOUND MEMBS        ********    4.00  *******                                  ********

  3  EXCAVATION                ********  ******  ******* EXCAVATION $/CY                      3.50
                                                         EXCAVATION DEPTH                    15.00
                                                         EXCAVATION AREA                      0.00 = AREA OF TYPICAL FLOOR .

  4  SHEETING                  ********  ******  ******* SHEETING $/SF                        3.00
                                                         SHEETING DEPTH                      15.00
                                                         SHEETING PERIMETER                   0.00 = PERIMETER OF BLDG

  5  MEMBRANE WATERPROOF       ********  ******  ******* $/SF WALL                            0.50
                                                         WALL AREA                            0.00 = 0.
                                                         $/SF SLAB                            0.20
                                                         SLAB AREA                            0.00 = 0.

  6  MASONRY AND CAULKING      ********  ******  ******* MASONRY AND CAULK $/SF               1.25
                                                         LINEAR FT CORE WAL/FL                0.00 = PERIM OF CORE+4 CROSS WALLS

  7  FIRST FLOOR CORE WALL     ********  ******  ******* 1ST FL CORE WALLS $/SF               8.00
                                                         LINEAR FT CORE WALLS                 0.00 = PERIM OF CORE + 2 CROSS WALL

  8  FIRST FLOOR FINISH        ********  ******  ******* 1ST FL FINISH $/SF                   4.00
                                                         AREA SO FINISHED                     0.00 = AREA OF FIRST FLOOR

  9  ROOF+SHEET MET,NO INS     ********  ******  ******* $/SF OF ROOF                         0.50

 10  MISC IRON                 ********  ******     0.20                                  ********

 11  WINDOW WALL, 1ST FL       ********  ******  ******* $/SF                                 8.00
                                                         NO. OF LINEAR FEET                   0.00 = PERIM 1/2 WAY BET CORE & FAC

 12  STOREFRONT, 1ST FL        ********  ******  ******* STORE FRONT 1ST FL $/SF              8.00
                                                         NO. OF LINEAR FEET                   0.00 = PERIM AT CORE + 2 MODULE OUT
```

Figure 6—Typical Cost Assumptions

The actual basis on which the calculation for a particular item is made is implied by the location of asterisks—i.e., the one column of the four that has no asterisks is the current basis for cost computation for that item. For example, demolition is normally assumed at zero dollars, since that item cost is most often part of a separate contract. Structural foundation members are assumed at 4% of the cost of the base building. Excavation, on the other hand, is computed on the basis of $3.50 per cubic yard times the volume of excavation (=15 feet × area of typical floor). Figure 7 indicates how the cost items are aggregated to form the cost categories shown in Figure 4.

The user can easily switch the basis and numerical values for computation of any cost item by the command

```
                           DOLLARS________
                           PCT____________
ENTER COST DATA, ITEM      SQ FT ________;
                           UNIT PRICE_____;
```

By giving the commands

```
ENTER COST DATA, ITEM 2 SQ FT. 1.20;
ENTER COST DATA, ITEM 3
UNIT PRICE 4.00, 20, 18000;
```

the user could change the basis of the structural foundation members from 4% of the base building cost to $1.20 per gross square foot of building, and change the values in the excavation computation to $4.00 per cubic yard times a 20 foot basement over an 18,000 square foot area.

Two additional commands are available to control the cost computation. One is of a direct multiplier nature, and is given as the Engineering News Record index

```
ENR COST INDEX,________;
```

The internal costs have been assumed on the basis of an ENR = 700. An externally supplied value of

```
                COST        SUMMARY      GROUPINGS

            CATEGORY                                        ITEMS

         1  SITE WORK                                  1
         2  FOUNDATION                                 2 3 4 5 39
         3  SUPERSTRUCTURE                             35
         4  EXTERIOR WALL                              11 13 29 31 38
         5  ARCHITECTURAL FINISHES                     6 7 8 9 10 12 14 15 16 17 18 19
                                                       20 21 22 23 24 34
         6  ELEVATORS                                  25 33
         7  PLUMBING                                   27 28
         8  HVAC                                       26
         9  ELECTRICAL                                 30
        10  GENERAL CONDITIONS                         32 36 40 41 42
        11  GC FEE                                     37
        12  CONTINGENCY                                44
        13  TENANT                                     43
        14  EQUIPMENT, FURNITURE                       45
        15  OTHER                                      46 47 48 49 50
SAVE BOP JOB, FILE 121

        BOP JOB     HINES, NO. 2 NEW ORLEANS     SAVED IN FILE    121
```

Figure 7—Cost/Summary Groupings

ENR = X will cause multiplication of all unit price type costs by a factor of X/700. A second command,

COST VS HEIGHT CURVE, ______________ ;

allows the user to specify the ordinates (costs) of a normalized cost vs. height curve at the abscissae (number of stories) of 1, 20, 40, 80. The curve is generally concave upwards, with a valley of 1.0 around 20 stories. Multiplicative effects of this curve are included along with the ENR COST INDEX.

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centro de educación continua
facultad de ingeniería, unam

ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

TECNICAS DE ANALISIS FINANCIERO APLICADAS A LA EVALUACION INTEGRAL DE UN PROYECTO DE CONSTRUCCION.

(15)

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15. TECNICAS DE ANALISIS FINANCIERO APLICADAS A LA EVALUACION INTEGRAL DE UN PROYECTO DE CONSTRUCCION.

Enrique Tercero Barragán

CONESCAL 32, Junio, 1974.

TECNICAS DE ANALISIS FINANCIERO APLICADAS A LA EVALUACION INTEGRAL DE UN PROYECTO DE CONSTRUCCION.

Ing. Enrique Tercero Barragán *

OBJETIVOS

La finalidad de este trabajo es la de presentar, con fines de divulgación, una metodología que hasta ahora se ha venido aplicando tan sólo para evaluar proyectos de desarrollo industrial, agropecuario y de infraestructura física, con la pretensión de explorar las posibilidades de su aplicación a proyectos de desarrollo económico, cuya rentabilidad no ha sido estudiada hasta ahora con la necesaria profundidad. Concretamente me refiero a los proyectos de desarrollo educativo. Existe a la fecha muy poca experiencia al respecto, no solamente en países en vías de desarrollo, los que naturalmente requieren con más urgencia la aplicación de estas técnicas, sino también en países en franco desarrollo. No obstante, existen estudios específicos sobre este terreno, casi virgen; que ya van arrojando resultados muy satisfactorios.

El contenido de este trabajo se encuentra dividido en dos partes fundamentales. La primera es un planteamiento teórico de la naturaleza de la metodología propuesta, con sus alcances y sus limitaciones; la segunda parte es la presentación de un caso de aplicación en la que se discuten los pormenores operativos de la metodología propuesta.

PRIMERA PARTE. PLANTEAMIENTO DE LA METODOLOGIA

1. La metodología del análisis de sistemas.

Para los fines de esta exposición y buscando proporcionar a la técnica expuesta una adecuada estructura conceptual, se pueden identificar cinco pasos básicos en un proceso de análisis de sistemas.

A) Definición de objetivos
B) Formulación de medidas de efectividad
C) Generación de alternativas
D) Evaluación de las alternativas
E) Selección de la alternativa preferida

A continuación se describen, de una manera más específica, la naturaleza de cada uno de esos pasos.

A) Definición de objetivos. Este paso tan obvio no tendría tanto valor, si no fuera ignorado tan frecuentemente. Por ejemplo, en los cursos de diseño de sistemas, los estudiantes reaccionan típicamente yéndose inmediatamente a los detalles de elementos de un sistema propuesto. "¿Objetivos? " dicen ellos," ¿quién los necesita?, comencemos a trabajar y diseñemos". Sin embargo, esta clase de respuestas no solamente se encuentra entre principiantes, profesionales de todas clases se ven envueltos en situaciones similares.

De hecho, una gran parte del trabajo del diseñador consiste en desafiar objetivos, vagamente definidos por clientes o profesionales de otras áreas, y así identificar los propósitos fundamentales de un sistema.

En general, para los fines de esta exposición, se puede distinguir entre las siguientes clases principales de objetivos:

i) *Eficiencia económica pura.* La maximización de las ganancias obtenidas sobre determinadas inversiones, prescindiendo de quien las pueda acumular o a costo de quien.

ii) *Redistribución de ingresos.* La promoción de beneficios de cierto tipo específico a expensas de otros de tipo diferente, tales como inversiones gubernamentales en obras públicas para el desarrollo de una determinada región de un país.

iii) *La satisfacción de necesidades urbanas o rurales urgentes,* que no siempre pueden ser justificadas a través de beneficios económicos directos pero cuya atención es de gran valor para la comunidad, tales como pueden ser algunos proyectos de salud pública o la creación de áreas de recreo.

Cada una de estas clases de objetivos tienen sus méritos propios, sin embargo, la persona u organismo

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* Técnico del CONESCAL

responsable de un proyecto debe ser siempre especialmente suspicaz con respecto a los objetivos económicamente injustificables: ya que mientras que los recursos se consagran válidamente a ellos cada día, debe también indicarse que existen promotores de proyectos específicos que no pueden ser defendidos en terrenos convencionales, pero que tratan de encubrirlos con el interés público. Es extremadamente difícil distinguir entre recursos meritorios y falsos para el interés público, de ahí la insistencia en que un responsable de proyecto deba ser muy cuidadoso en estos terrenos.

B) *Formulación de medidas de efectividad.* El fin último del proceso de análisis consiste en desarrollar una apreciación de la efectividad relativa, con la cual las alternativas seleccionadas cumplen con un conjunto determinado de objetivos.

Esto no se puede lograr sin tener algún medio para especificar en qué grado deben lograrse los objetivos; por lo tanto deberán definirse índices de funcionamiento, que estén comprendidos dentro de una escala cuantitativa, que permita precisamente establecer, en forma objetiva, ese grado en que los proyectos alternativos analizados satisfacen las metas propuestas.

La selección de las medidas de efectividad es esencial, porque en gran parte determina el diseño o configuración final de un sistema. Esto puede ilustrarse mediante un simple ejemplo:

Supongamos que se requiere diseñar un sistema de transporte masivo de bajo costo. ¿Cómo podrían expresarse los costos de tal manera que lo barato pueda ser identificado?

En pesos por pasajero — kilómetro?

En pesos por viaje?

En pesos por vehículo — kilómetro?

Cada una de estas cantidades podría ser utilizada para medir la eficiencia del sistema de transporte.

El costo de pasajero — kilómetro podría favorecer viajes largos y de gran densidad de pasajeros.

La utilización del costo por viaje como un índice, nos llevaría a la definición de una red densa, con poco espaciamiento entre estaciones.

Finalmente, la consideración del costo por vehículo—kilómetro tiende a promover el uso de vehículos pequeños en la red.

La selección de la medida de efectividad, en este caso representaría una decisión de diseño. Esto permite dar una idea clara de la importancia considerable y del estudio que hay que dedicar a esta selección.

Para mostrar en cambio, cómo la selección de una inadecuada medida de efectividad puede excluir la consideración de buenas soluciones, consideremos la situación en donde la comunicación entre dos comunidades es difícil, porque los canales de circulación están sobre-cargados. Si la medida de efectividad para juzgar el comportamiento del sistema es la capacidad de un canal de circulación, la solución obvia sería aumentar el número de canales. Sin embargo, se estarían excluyendo otras soluciones posiblemente mejores, tales como la regulación del tráfico para disminuir los picos o la compactación (animando a la gente a utilizar transporte colectivo en lugar de automóviles, por ejemplo). Esto podría verse como factor relevante si los índices de comportamiento fueran redefinidos.

Por último, cabe mencionar que en ciertos casos se introducen en la selección de las medidas de efectividad algunas complejidades adicionales a causa de la relación frecuentemente no-lineal entre estas medidas y los valores que intentan representar, como veremos más adelante, por lo que en la práctica deberán aplicarse límites y rangos a las medidas de efectividad.

C) *Generación de alternativas.* Dado que el propósito del análisis es el descubrimiento y especificación de soluciones preferidas, es necesario hacer hincapié en la necesidad de dedicar un considerable esfuerzo a la exploración de un amplio rango, de posibles soluciones. Los interrogantes principales en este caso son:

¿Cómo deberán ser identificadas estas soluciones?

En qué orden?

¿Cuántas y cuáles deberán ser observadas?

¿En qué grado?

Con excepción de problemas muy específicos, para los cuales existe incluso una formulación matemática estricta, no parece razonable ni factible considerar todas las posibilidades, y aun cuando fuese posible pensar en todas las combinaciones, el sentido común sugiere que la investigación de todas las alternativas no es recomendable; algunas no son lo suficientemente diferentes para garantizar un tratamiento separado y algunas están claramente dominadas por otras. En este sentido es importante ser selectivo en la búsqueda de las alternativas, ya que los recursos son limitados.

Sin embargo, es importante determinar, como se verá más adelante, la sensibilidad de una solución a los cambios en sus parámetros principales, para identificar las alternativas fundamentales a considerar.

Sea como fuere, lo cierto es que no obstante la naturaleza parcialmente intuitiva de este aspecto de generar alternativas, es conveniente señalar lo deseable que es considerar muchas alternativas en lugar de pocas El desarrollo de las computadoras electronicas ha aumentado enormemente la habilidad del diseñador y del analista para hacer esto, y ha hecho posible el desarrollo de estudios comprensivos de una manera eficiente y ordenada. Resumiendo, la generación deliberada de un amplio rango de alternativas es esencial para el análisis de sistemas.

D) Evaluación de alternativas. Es conveniente en este punto distinguir cuidadosamente entre la evaluación de los efectos de cada una de las alternativas y la selección de una solución particular.

En esencia, la evaluación de alternativas consiste en asociar cada alternativa con sus efectos, beneficios, costos, impactos sobre la comunidad, efectividad funcional, etc. Estos efectos, se estiman generalmente mediante la utilización de modelos matemáticos de varias clases, los cuales son esenciales en los análisis a gran escala.

La selección es diferente. Consiste en un examen de los efectos (tomados de la evaluación) de cada alternativa, una comparación de sus valores relativos y una decisión acerca de cuál conjunto es preferible. Mientras que la evaluación, como ha sido definida aquí, es un proceso mecánico, la selección es principalmente un problema de juicio y de valor. Esto implica que las decisiones importantes, no deben ser delegadas a una fórmula matemática sin razonamiento.

E) Selección de la alternativa preferida. Finalmente, la selección es el arte de balancear todas las consecuencias. Implica juicios valorados de las medidas de efectividad deducidos objetivamente y obtenidos como resultado del proceso de evaluación.

La selección no es un problema solamente técnico, sino de índole, en muchos casos, político. El papel del analista es entonces el de ayudar al proceso de decisión, eliminando tantas incertidumbres técnicas como sea posible.

De esta manera, el análisis de sistema es fundamentalmente un esfuerzo por definir objetivos y alternativas para el que toma decisiones y luego proveerlo con la información relevante según preferencias.

2. EL ANALISIS FINANCIERO DE PROYECTOS

2.1 Su naturaleza y alcances.

Es conveniente aclarar aquí, que el significado preciso que se dará al término "Proyecto" en esta exposición, posee un contenido diferente , al del sentido usual de "Diseño", tanto arquitectónico como estructural y de instalaciones, con el que suele emplearse.

Esto es importante, ya que es frecuente que al hablar de "evaluación de proyectos" en el medio de construcciones escolares, se está hablando en realidad de evaluación de diseños. Indudablemente, al evaluar diseños se están aplicando los principios del análisis de sistemas que se acaban de esbozar. Concretamente, el criterio de costos-límite que suele emplearse es una medida de efectividad que permite evaluar diferentes diseños y hacer inclusive una posterior selección del mejor. Sin embargo, el significado concreto que aquí se da al término "proyecto" es más bien el de "proyecto de inversión", es decir, al hablar de proyecto no solamente hablamos del o los diseños que se requieren para la realización de un conjunto de instalaciones educativas y de su construcción misma, sino que hablamos también de todos los otros conceptos de costo que involucra normalmente una inversión en un complejo educativo, tales como la operación del sistema, su mantenimiento, el mobiliario y el equipo, la adquisición de terrenos, el personal administrativo y docente necesario, los programas y cursos de capacitación necesarios y las asesorías técnicas utilizadas para la implementación de las diversas fases del proyecto.

Evidentemente, lo anterior implica que el análisis motivo de este trabajo abarque gran parte del horizonte de planeación del proyecto. Es decir, el parámetro tiempo tiene una importancia capital dentro del análisis financiero.

2.2 Sus objetivos.

Siguiendo los pasos fundamentales de un proceso de análisis de sistemas, los objetivos buscados al implementar un determinado proyecto, desde el punto de vista financiero, pueden ser de tres clases básicas:

A) Que la inversión sea rentable, es decir, que los beneficios que se obtengan como producto de la implementación del proyecto analizado excedan en un atractivo margen a los costos que involucra dicha implementación.

B) Que la inversión sea simplemente autosoportable o autofinanciable, es decir, que si bien los beneficios obtenidos como producto de la implementación del proyecto analizado no exceden en un margen atractivo, desde el punto de vista privado, a los costos que involucra dicha implementación, si los exceden con un margen suficiente para lograr un equilibrio en el flujo de fondos durante el período de análisis del proyecto

C) Que aun cuando el proyecto analizado no produzca beneficios directos, los beneficios indirectos que se obtienen, cuantificados en términos monetarios, exceden en un margen razonable a los costos involucrados en su implementación.

Al tipo de beneficios indirectos que se obtienen en esta última clase de proyectos, se les suele denominar beneficios sociales. Sin embargo, es necesario tener mucho cuidado con esta clase de proyectos, que generalmente son de tipo público, ya que existe la tendencia a menospreciar los resultados de su evaluación, aunque en muchos casos se trate de inversiones de gran cuantía para el erario nacional.

En este sentido la tendencia observada en algunos países de la región latinoamericana, es la de procurar evitar esta última clase de proyectos, buscando en alguna forma el convertirlos en autofinanciables mediante medidas que permitan que el proyecto produzca algún beneficio directo que lo convierta en tal, medidas tales como cuotas de aportación de los usuarios del sistema.

La conciencia de esta necesidad ha surgido precisamente a consecuencia del empleo de las técnicas de evaluación que se están exponiendo en este trabajo.

2.3 Sus medidas de efectividad.

En términos generales la efectividad de un proyecto, desde el punto de vista financiero, se suele medir mediante cualquiera de los cinco siguientes criterios.

A) Relación beneficio/Costo
B) Valor presente de los beneficios netos
C) Tasa interna de retorno
D) Costo específico de capital.
E) Período de recuperación

En todos y cada uno de los criterios mencionados, la materia de análisis es el flujo o corriente de fondos durante un horizonte económico de estudio, cuya extensión se asigna de una manera más bien arbitraria, en función de experiencias previas en proyectos similares.

Dado que los fines de este trabajo no son didácticos sino puramente ilustrativos, a continuación se pretenderá describir, en términos muy generales y aún a riesgo de ser demasiado simplistas, en qué consiste cada uno de los cinco criterios enunciados. Sin embargo, previamente a esta descripción, es conveniente explicar y aclarar un concepto que resulta de vital importancia para la adecuada comprensión de los criterios mencionados, y es el del "valor presente" o "valor actualizado", o "valor descontado" de una corriente o flujo de dinero.

Supóngase que se tiene una suma de dinero cuyo valor se incrementa anualmente en un cierto porcentaje fijo "r" a partir de un valor inicial K_0

Al cabo del primer año, el nuevo valor de esa suma es ahora:

$$K_1 = K_0 \ (1 + r)$$

En donde r está expresado como fracción decimal.

Al cabo del segundo año, el valor de la suma será:

$$K_2 = K_1 \ (1 + r) = K_0 \ (1 + r)\,(1 + r)$$
$$= K_0 \ (1 + r)^2$$

Al cabo del tercer año:

$$K_3 = K_2 \ (1 + r) = K_0 \ (1 + r)^2 \ (1 + r)$$

Por inducción matemática, al cabo de "n" años:

$$K_n = K_0 \ (1 + r)^n \text{ ------------ } (1)$$

Supóngase ahora el problema inverso, es decir, dada una suma de dinero cuyo valor incrementado al cabo de "n" años es "K", se quiere saber su valor inicial en el año cero, suponiendo que el porcentaje o tasa de incremento anual haya sido "r".

En ese caso bastará con despejar de la expresión (1), la incógnita buscada:

$$K_0 = \frac{K_n}{(1 + r)^n} \text{ ---------- } (2)$$

A este valor "K_0" se le denomina "valor presente" o "valor actualizado", de una suma de dinero erogada o ingresada en el año "n" de un horizonte económico de análisis.

Para el caso de la expresión (1) se hablaba de una tasa de incremento anual "r", es decir el valor "K_n" es un valor incrementado; de manera análoga, en el caso de la expresión (2) se habla usualmente de una tasa de descuento "r", y por esta razón al hablar del valor "K_0" se le llama también "valor descontado".

A la tasa "r" se le llama entonces "tasa de descuento" o también "tasa de actualización".

Explicados estos conceptos se puede ya pasar a la descripción de los criterios de efectividad mencionados al comienzo de este capítulo.

A) Relación beneficio/costo. En síntesis, este criterio se expresa como un cociente de Ventajas/Desventajas. Las ventajas son los beneficios de la inversión realizada, bien sea como un resultado de la repercusión que dicho proyecto tiene sobre la economía regional o nacional del país en que se va a realizar, bien sea como resultado directo de la comercialización de la producción misma del proyecto en cuestión. Las desventajas son los insumos requeridos por el proyecto, es decir, los costos, no solamente durante la etapa de operación, sino eventualmente durante las fases de ampliación que pueda tener el proyecto en el horizonte económico de análisis que se esté considerando.

Concretando, supóngase que se tiene la siguiente corriente de costos y beneficios en un determinado proyecto, cuyo horizonte económico es de "n" años.

Beneficios	B_0	B_1	B_2	B_3		B_{n-1}	B_n
Costos	C_0	C_1	C_2	C_3	.....	C_{n-1}	C_n
Años	0	1	2	3		n−1	n

La relación beneficio/ costo de este proyecto es el cociente formado por la suma de la corriente de beneficios, llevado cada uno de ellos a valor presente (actualizado o descontado) dividida entre la suma de la corriente de costos, llevando también cada uno de ellos a valor presente.

Para llevar a valor presente los beneficios se tendría lo siguiente:

$$VP_{B_0} = B_0$$

$$VP_{B_1} = \frac{B_1}{1 + r}$$

$$VP_{B_2} = \frac{B_2}{(1 + r)^2}$$

$$VP_{B_n} = \frac{B_n}{(1 + r)^n}$$

Por tanto la suma de estos valores sería:

$$\sum_{i=0}^{n} VP_{B_i} = \sum_{i=0}^{n} \frac{B_i}{(1 + r)^i}.$$

En forma análoga, para los costos se tendría:

$$\sum_{i=0}^{n} VP_{C_i} = \sum_{i=0}^{n} \frac{C_i}{(1 + r)^i}$$

Y por consecuencia:

$$\text{Relación B/C} = \frac{\sum_{i=0}^{n} \frac{B_i}{(1 + r)^i}}{\sum_{i=0}^{n} \frac{C_i}{(1 + r)^i}}$$

Fijada una tasa de actualización, se dice que un proyecto es "rentable" o "viable", bajo este criterio, si el valor del cociente calculado no es menor de la unidad.

Obsérvese que el valor de esta relación depende sustancialmente de la tasa de descuento que se escoja, sin embargo, la selección de la misma resulta un tanto arbitraria ya que su valor está en función de diversos factores, tales como el índice de crecimiento en los costos de los materiales, el índice de crecimiento en el costo de la mano de obra, la tasa inflacionaria promedio prevaleciente en el país, e inclusive de posibles devaluaciones monetarias durante el horizonte económico de análisis; la forma en que cada uno de estos factores influye en el valor de la tasa de actualización no es una función conocida a priori, razón por la cual lo usual es asignarle un valor basado en experiencias previas en proyectos similares.

Esta relativa arbitrariedad en la elección de la tasa de descuento es justamente uno de los principales defectos que tradicionalmente se le han atribuído a la relación B/C. Sin embargo, si se efectúa un análisis de sensibilidad del cociente para diversos valores de la tasa, puede subsanarse en gran parte ese defecto.

Otros defectos importantes de los que adolece este criterio son, primeramente, el de que su conocimiento no aporta información sobre los costos de oportunidad de los recursos asignables al proyecto, cuando se pretende aplicarlos a otros usos; y segundo, el de que para tasas de descuento elevadas este criterio desalienta el uso intenso o concentrado de capital como el que tiene lugar en proyectos de formación de infraestructura, porque las inversiones iniciales son generalmente altas, mucho mayores que los beneficios anuales que al ser actualizados pierden significativamente su valor. Dado que en la práctica, la fijación de las tasas de descuento por utilizar para determinado tipo de proyectos se hace en forma convencional, por acuerdo entre diversos organismos, nótese la repercusión económica que podría tener para la industria de la construcción de un país, una medida tendiente a elevar esas tasas en forma arbitraria.

B) Valor presente de los beneficios netos. Este criterio difiere del anterior en que, en vez de estar expresado como un cociente cuyo valor está dado en unidades adimensionales, queda expresado en unidades monetarias.

Dicho brevemente, el valor presente de los beneficios netos de un proyecto es la suma de la corriente de las diferencias entre los beneficios y los costos asignados a cada período del horizonte económico de un proyecto; expresado algebraicamente:

$$\text{VPBN} = \sum_{i=0}^{n} \frac{(B_i - C_i)}{(1+r)^i}$$

Si bien este criterio adolece del mismo defecto que el anterior, de depender de una tasa de actualización fijada en forma relativamente arbitraria, defecto que como ya se indicó, se puede subsanar mediante un adecuado análisis de sensibilidad, posee en cambio la ventaja de permitir el uso de modelos matemáticos para la selección óptima de un conjunto de proyectos de inversión valuados individualmente con ese criterio.

C) Tasa interna de retorno. Para estimar la productividad que dentro de un proyecto tienen los recursos empleados, se conviene en emplear el concepto de tasa interna de retorno, o tasa que hace iguales los valores presentes, a un horizonte económico de análisis dado, de las corrientes de costos y beneficios asociados a la iniciativa.

Algebraicamente, "L" es la tasa interna de retorno propia de una iniciativa si y sólo si:

$$\sum_{i=0}^{n} C_i \; (i + L)^{-i} = \sum_{i=0}^{n} B_i \; (1 + L)^{-i}$$

Este criterio implica la búsqueda de la raíz real de la ecuación anterior. Cuando "L" no es la única, resulta inadecuado emplearla como índice de evaluación, ya que por definición este debe ser unívoco; sin embargo, este caso no es frecuente y sólo ocurre cuando existen gastos de consideración previstos hacia los últimos años del horizonte económico de análisis. Dentro del orden práctico, su cálculo manual es laborioso, pero esto en la actualidad ya no representa ningún obstáculo significativo, ya que aún con una pequeña computadora digital de escritorio (y aun más de bolsillo) se le determina de manera sencilla y muy rápida.

Como ya se dijo este criterio tiene la ventaja de revelar explícitamente la productividad real del proyecto, además de representar una base muy consistente para juzgar tanto su viabilidad económica como su prioridad relativa, respecto de un conjunto dado de proyectos de inversión.

De hecho, aún cuando también los dos criterios anteriores se utilizan para jerarquizar un conjunto de proyectos de inversión, el criterio más usual para juzgar de la prioridad relativa de un conjunto de proyectos es justamente su tasa interna de retorno.

D) Costo específico de capital. Por definición el costo de capital es el precio que el organismo responsable de un proyecto debe pagar por el uso de los fondos de inversión que se requieren destinar a un proyecto determinado.

En términos algebraicos, la tasa "j" es el costo específico de capital de una inversión, si y sólo si:

$$\sum_{i=0}^{n} K_i \; (1 + j)^{-i} = \sum_{i=0}^{n} P_i \; (1 + j)^{-i}$$

En donde "K_i" es el desembolso de una inversión en el período i y "P_i" es la suma del pago del principal más el pago de los intereses de la misma inversión correspondientes al período i de amortización.

En realidad, este criterio es complementación del anterior, ya que para poder considerar que un proyecto es rentable, económicamente hablando, el requisito mínimo indispensable a la luz de estos criterios, es que su tasa interna de retorno sea siempre mayor que su costo específico de capital.

E) Período de recuperación. Se denomina período de recuperación a aquel período para el cual la suma de los beneficios netos acumulados a valor presente, iguala al monto total de los desembolsos de la inversión efectuada en este proyecto.

Expresado algebraicamente esto significa que el período de recuperación es aquel valor de "m" que satisface la siguiente igualdad:

$$\sum_{i=0}^{m} K_i \; (1 + r)^{-i} = \sum_{i=0}^{m} (B_i + C_i) \; (1 + r)^{-i}$$

Al igual que la relación beneficio/costo tiene el defecto de depender de una tasa de actualización arbitrariamente elegida; pero además tiene el defecto de ignorar parcialmente la información de los flujos de beneficios y costos, es decir de toda aquella porción de esos flujos que quedan más allá, justamente, del período en cuestión.

En general, se le considera el más inconsistente de todos los criterios mencionados. Usado como un criterio de jerarquización de proyectos, tiende a dar mayor preferencia a aquellos proyectos que ofrecen una recuperación de la inversión inicial a corto plazo sobre aquéllos cuya recuperación de esa misma inversión se realiza a más largo plazo. Es decir que este criterio resulta totalmente inadecuado para juzgar proyectos de formación de infraestructura, en los que, como ya se señaló anteriormente, el monto de la inversión inicial es muy grande en comparación con los beneficios netos que se obtienen en el proyecto a corto plazo.

Lo más usual aunque no lo más correcto, es calcular este índice sin actualizar valores. De esta forma resulta un criterio muy sencillo de calcular y por lo tanto, si se desea obtener en forma rápida un INDICE que proporcióne una idea, aunque sea muy burda de la situación del proyecto, este criterio puede ser muy útil en una primera aproximación.

2.4 Observaciones generales sobre su uso. Si bien es cierto que cada uno de los criterios estudiados presenta individualmente un conjunto de ventajas y desventajas que, al comparar conceptualmente dichos criterios entre sí, hacen que se revelen como más consistentes los de tasa interna de retorno, costo específico de capital y valor presente de los beneficios netos, la fuerza de la costumbre ha consagrado el uso de los dos restantes. Por otra parte, la verdad es que ninguno de esos cinco criterios, por sí solo, refleja adecuadamente la situación económico financiera de un proyecto, por lo que es altamente recomendable el cálculo y uso simultáneo de todos ellos para obtener una mejor imagen de un determinado proyecto. Si se tiene en cuenta que la existencia de equipos de procesamiento electrónico de datos, no solamente de mediano o gran tamaño, sino aun los llamados minicomputadores, ya sean éstos de salón, de escritorio o aun de bolsillo, es cada vez más frecuente en la región latinoamericana y también en la del Caribe, este cálculo simultáneo es perfectamente factible obtenerlo, con un consumo de tiempo realmente mínimo, mediante el uso de uno cualquiera de esos equipos.

SEGUNDA PARTE: APLICACION DE LA METODOLOGIA

A) Descripción del proyecto

Aun cuando no pertenece al campo específico de las construcciones escolares, el ejemplo que se presenta a continuación posee un conjunto de características que permiten visualizar, en forma bastante sencilla, los principales alcances de la metodología anteriormente explicada.

El proyecto en cuestión es un proyecto público de remodelación del Centro de la ciudad de Toluca, en el Estado de México, actualmente en proceso de construcción.*

La obra por ejecutar incluye los siguientes conceptos:

1. REMODELACIONES.

1.1 Portales:

a) Pavimento y techo
b) Fachadas exteriores
c) Fachadas interiores

Suma parcial: $ 3,500,000.00

1.2 Fachadas de:

a) Iglesia Santa Veracruz
b) Palacio Municipal
c) Cúpula Cámara de Diputados
d) Fachada Belisario Domínguez

Suma Parcial: (1.2) $ 1,100,000.00
Suma parcial: (1) $ 4,600,000.00

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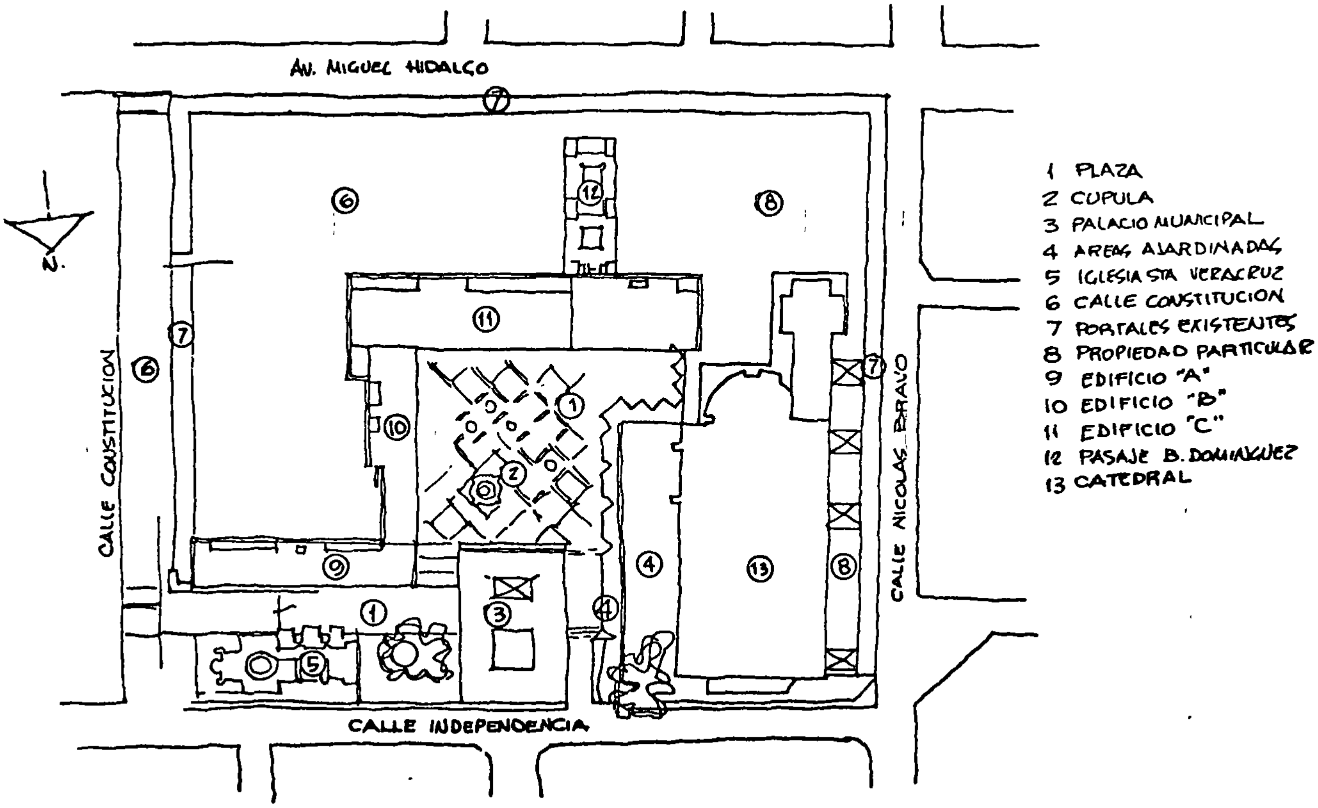
* El autor desea testimoniar su agradecimiento al Presidente Municipal de Toluca, Lic. Arturo Martínez Legorreta, así como al Dr. Melchor Rodríguez Caballero, por su gentileza al permitir la reproducción de este interesante proyecto.

2. OBRAS NUEVAS.

2.1 Edificio de Portales Nuevos
2.2 Estacionamientos.
Suma Parcial: (2) $ 24,000,000.00

3. OBRAS EXTERIORES.

3.1 Plaza
3.2 Calle Constitución
3.3 Pasaje Belisario Domínguez
3.4 Jardinería
Suma Parcial: (3) $ 5,600,000.00
Suma Total: $34,200,000.00



Al iniciar el estudio de evaluación, el problema fundamental que se planteaba a las autoridades municipales responsables del proyecto, era la consecución de los fondos necesarios para financiar la inversión. La solución que se le dio al problema fue la siguiente:

Los portales, las fachadas y las obras exteriores serían amortizadas por la comunidad, mediante una derrama realizada en proporción a los valores catastrales de los terrenos propiedad de los moradores de la zona de influencia de las obras, previa formación de un consejo de cooperadores integrado por representantes de esa comunidad y estableciendo el respectivo convenio de cooperación entre el municipio y dicho consejo. Este convenio, establecido después de haber realizado el necesario estudio de derrama, sirvió de base para negociar el financiamiento de las correspondientes obras.

En cuanto a las obras nuevas, puesto que el edificio estaba diseñado para ubicación de oficinas y locales comerciales y el estacionamiento sería administrado comercialmente también, se podía hacer la necesaria evaluación económico-financiera de esa parte del proyecto para determinar su rentabilidad y si era o no auto-financiable. Los resultados de este estudio serían el documento que serviría de base para la negociación del financiamiento de esta parte del proyecto con la banca privada.

TABLA 1: REMODELACION DEL CENTRO DE TOLUCA COSTOS CONSIDERADOS EN EL ESTUDIO

1. COSTO EDIFICIO	M2	$/M²	$	SUMAS PARCIALES
Terreno:	2,682.45 x	2,000.00	5'364,900	5'364,900
Edificio:				
–Construcción (sin incluir cimentación)			19'866,397	
–Cimentación			1'000,000	
–Estudios y Proyectos 5%			1'043,320	
–Supervisión y administración 5%.			1'043,320	22'953,037
				28'317,937
2. COSTO DE ESTACIONAMIENTO				
Terreno:	5,684.00 x	1,000.00	5'684,000	5'684,000
Edificio:				
–Construcción			2'933,940	
–Estudios y proyectos 5%			146,697	
–Supervisión y administración 5%			146,697	3'227,334
				8'911,334
3. COSTO DE OBRAS EXTERIORES				
Terreno:	5,240.00 x	1,000.00	5'240,000	5'240,000
Edificación:				
–Construcción remodelaciones			4'575,950	
–Construcción obras exteriores			5'588,401	10'164,351
–Estudios y proyectos 5%				508,218
–Supervisión y administración 5%				508,218

TABLA 2: REMODELACION DEL CENTRO DE TOLUCA
RENTAS CONSIDERADAS EN EL ESTUDIO
EDIFICIO

PARTE	AREA	VALOR UNITARIO DE RENTA			RENTA MENSUAL TOTAL		
		PESIMISTA	MEDIO	OPTIMISTA	PESIMISTA	MEDIO	OPTIMISTA
SOTANO	2,682.45	5	10	15	13,412.25	26,824.50	40,236.75
PLANTA BAJA	2,682.45	60	65	70	160,947.00	174,359.25	187,771.50
MEZZANINE	1,831.94	60	65	70	109,916.40	119,076.10	128,235.80
DESPACHO	7,244.38	20	25	30	144,887.60	181,109.50	217,331.40
			T O T A L		429,163.25	503,495.35	573,575.45

VALOR PESIMISTA RENTA ANUAL: $ 429,163.25 x 12 = $5'149,959

VALOR MEDIO RENTA ANUAL: $ 503,495.35 x 12 = $6'039,818

VALOR OPTIMISTA RENTA ANUAL: $ 573,575.45 x 12 = $ 6'882,905

B) Metodología empleada

Después de efectuar la necesaria evaluación técnica del proyecto que incluyó la revisión de áreas, cantidades de obra, materiales a utilizar, cantidad de mano de obra requerida, precios unitarios aplicados, y presupuestos, se pasó a la evaluación financiera propiamente dicha, procediendo en la siguiente forma:

1. *Determinación de ingresos.*

1.1 *Estudio de rentas:* Se realizó una investigación de mercado para definir el valor factible a cobrar por concepto de rentas de locales comerciales y de despachos. De esta manera se obtuvieron tres valores, uno pesimista, uno medio y uno optimista que aparecen en la tabla 2.

1.2 Estudio de posibles ingresos por concepto de cobro de derechos de estacionamiento de pensionados y estacionamiento público, cuyos resultados aparecen descritos en la tabla 4.

2. *Egresos o deducciones.*

2.1 *Desocupación.* Aunque por una investigación de mercado se obtuvo que la desocupación en los edificios, podría estimarse en un 2% del importe de las rentas, se estimó conveniente considerar hasta un 5%, ya que a mediano plazo seguramente habrá un incremento de construcción de edificios comerciales (Ver tabla 3)

2.2 *Mantenimiento y administración del edificio.* Se consideró que para garantizar un excelente mantenimiento y conservación del edificio es necesario estimar su costo en un 3% anual sobre el valor de la construcción (ver tabla 3).

2.3 *Agua y luz.* El porcentaje para este concepto se determinó por investigación de mercado (Ver tabla 3).

2.4 *Impuestos.* 3.5% de timbres sobre el valor global de las rentas (Ver tabla 3).

2.5 *Impuesto predial.* De acuerdo con la ley general de catastro del Edo. de México se aplicó el 0.525% sobre el valor catastral de los edificios (ver tabla 3).

2.6 *Seguros.* Se consideró un 8 al millar sobre el costo de construcción del edificio sin incluir la cimentación (ver tablas 1 y 3)

2.7 *Depreciación de los edificios.* Se consideró una vida económica útil de 25 años y una depreciación de tipo lineal (ver tabla 3.)

2.8 *Costos de operación para el estacionamiento.* (Ver tabla 5 del anexo).

2.9 *Mantenimiento y conservación del estacionamiento.* Para este caso se consideró el 1% del valor de la construcción, ya que la calidad entre los acabados del estacionamiento y los edificios amerita tal diferencia (ver tabla 6).

2.10 *Agua y luz para el estacionamiento.* (Ver tabla 6).

2.11 *Impuestos para el estacionamiento.*

a) Ingresos mercantiles: 4% sobre el valor de las rentas. (Ver tabla 6).

b) Impuesto predial: Idem. que para los edificios

c) Depreciación: Idem que en edificios.

3. *Hipótesis de la evaluación*

Para llevar a cabo el análisis se hicieron las siguientes hipótesis o consideraciones:

3.1 Los ingresos por concepto de renta, para el edificio, se incrementan un 10% bianual a partir de 1976 y este incremento se mantiene durante 10 años, después de los cuales, el ingreso mencionado no sufre ya ningún incremento.

3.2 Las deducciones anuales, exceptuando la correspondiente al impuesto predial, experimentan también un incremento bianual del 10% durante 10 años, después de los cuales sólo sufren un 1% anual de incremento.

3.3 Los ingresos por concepto de renta, para el caso del estacionamiento, experimentan un incremento del 10% en el segundo año del siguiente sexenio y luego se incrementan un 10% cada seis años hasta el final del período de análisis.

TABLA 3: REMODELACION DEL CENTRO DE TOLUCA
DEDUCCIONES ANUALES
EDIFICIO

			$
1. Desocupación:			
5% rentas:	Pesimista	0.05 x 5'149,959	257,348
	Medio	0.05 x 6'039,818	301,991
	Optimista	0.05 x 6'882,905	344,145
2. Mantenimiento y administración:			
3% valor edificio:		0.03 x 22'953.037	688.591
3. Agua y Luz:			
2% rentas:	Pesimista	0.02 x 5'149,959	102,999
	Medio	0.02 x 6'039,818	120,796
	Optimista	0.02 x 6'882,905	137,658
4. Timbres:			
3.5% rentas:	Pesimista	0.035 x 5'149,959	180,248
	Medio	0.035 x 6'039,818	211,394
	Optimista	0.035 x 6'882,905	240,902
5. Predial:			
.525% valor catastral:		0.00525 x 28'317,937	148,669
6. Seguros:			
8 al millar:	Costo de construcción del edificio sin cimentación.		
		0.008 x 19'866,397	158,931
7. Depreciación:			
4% valor edificación		0.04 x 22'953,037	918,121

[illegible] supuestos casos en que la diferencia entre [illegible] y los fondos, resulte negativa se considera que es necesario incurrir en un refinanciamiento. Mientras esta diferencia no se anule o se convierta en positiva, ese refinanciamiento se supone puede ser proporcionado por cualquier fuente de crédito, que no necesariamente tiene que ser la misma que aporta el financiamiento para la inversión inicial.

3.5 La tasa de interés considerada como más probable para el financiamiento de la inversión inicial, es de 15% sobre saldos insolutos semestrales.

3.6 El período de Amortización de la Inversión Inicial, se supuso igual a 10 años.

3.7 La tasa de interés considerada como más probable para los refinanciamientos es del 18% sobre saldos insolutos semestrales.

3.8 El período de Amortización de los refinanciamientos se supuso igual a 5 años.

3.9 Por último, se consideró que durante el tiempo en que se ejerce el crédito inicial, éste no devenga intereses.

4. *Resultados del análisis.*

En las tablas 6-A, 6-B y aparecen desarrolladas las corrientes de beneficios y costos durante un

TABLA 4: REMODELACION DEL CENTRO DE TOLUCA
ESTACIONAMIENTO
INGRESOS

1. ESPACIOS DISPONIBLES

60 espacios para pensionados
150 espacios para público

2. RENTAS:

Pensión: 150 $/mes
Tarifa al público· $ 3/primera hora, $ 1/hora subsecuente

3. OCUPACION CONSIDERADA:

2 horas/automóvil, promedio
3 automóviles/espacio x día 300 días de servicio

4. INGRESOS:

	$/año
60 x 150 x 12 =	108,000
12 x 150 x 300 =	540,000
	$ 648,000

TABLA 5: REMODELACION DEL CENTRO DE TOLUCA
ESTACIONAMIENTO
OPERACION

PUESTO	SALARIO/MES $	NUMERO DE TURNOS	TOTAL/MES $
ENCARGADO	2,000	1	2,000
2 CHECADORES	1,500	3	9,000
2 MOZOS	1,000	2	4 000
TOTAL			15,000

TOTAL ANUAL: $15,000 x 12 = $180,000

TABLA 6: REMODELACION DEL CENTRO DE TOLUCA
DEDUCCIONES ANUALES
ESTACIONAMIENTO

1. Administración		180,000
2. Mantenimiento: 1% valor edificio:	0.01 x 3'227,334	32,273
3. Agua y Luz		60,000
4. Ingresos Mercantiles: 4% renta:	0.04 x 648,000	25,920
5. Impuesto predial:	.525 x 8'911,334	46,784
6. Depreciación	0.04 x 3'227,334	129,093

$$\frac{344{,}977}{648{,}000} = 0.53$$

$$\frac{474{,}070}{648{,}000} = 0.53$$

TABLA 6–A
PROYECTO REMODELACION DEL CENTRO DE TOLUCA ALT 15
CUADRO DE FUENTES Y USOS DE FONDOS

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
FUENTES										
INGRESOS POR CONCEPTO DE RENTA	0.0	1.86	7.53	8.22	8.29	9.04	9.04	9.88	9.88	10.79
SUB–TOTAL VENTA	0.0	1.88	7.53	8.22	8.29	9.04	9.04	9.88	9.88	10.79
RECURSOS CREDITICIOS										
INVERSION INICIAL	10.49	15.74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
REFINANCIAMIENTO	1.63	3.64	0.58	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SUB–TOTAL CREDITO	12.12	19.38	0.58	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPRECIACION DEL AÑO ANTERIOR	0.0	0.0	0.53	1.05	1.05	1.05	1.05	1.05	1.05	1.05
SALDO DEL AÑO ANTERIOR	0.0	0.0	0.0	0.0	0.91	2.54	5.43	9.32	15.22	21.71
TOTAL DE FUENTES	12.12	21.26	8.64	9.27	10.25	12.63	15.52	20.25	26.15	33.55
USOS										
CONSTRUCCION	10.49	15.74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEDUCCIONES ANUALES	0.0	0.28	1.71	1.85	1.88	2.04	2.04	2.21	2.21	2.39
DEPRECIACION	0.0	0.53	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
SUB–TOTAL INVERSION	10.49	16.55	2.76	2.90	2.93	3.09	3.09	3.26	3.26	3.44
AMORTIZACION DE CREDITOS										
INVERSION INICIAL	1.63	4.08	3.90	3.45	2.99	2.54	2.09	1.63	1.18	0.73
REFINANCIAMIENTO	0.0	0.63	1.98	2.01	1.79	2.57	1.03	0.14	0.0	0.0
SUB–TOTAL AMORTIZACION	1.63	4.71	5.88	5.46	4.78	4.11	3.11	1.77	1.18	0.73
TOTAL USOS	12.12	21.26	8.64	6.36	7.71	7.20	6.20	5.03	4.44	4.17
SALDO PARA EL AÑO SIGUIENTE	0.02	0.0	0.0	0.91	2.54	5.43	9.32	15.22	21.71	29.38

TABLA 6–B

PROYECTO REMODELACION DEL CENTRO DE TOLUCA ALT 15
ANALISIS DE SENSIBILIDAD DE LOS
INDICES DE EVALUACION ECONOMICA

CORRIENTE DE BENEFICIOS # SUB-TOTAL VENTA
CORRIENTE DE COSTOS # SUB-TOTAL INVERSION

TASA	RELACION B/C	VALOR PRESENTE BENEFICIOS NETOS	ANO DE RECUPERACION
0.01	2.23	122.	7
0.02	2.16	104.	7
0.03	2.08	89.	8
0.04	2.00	76.	8
0.05	1.93	66.	8
0.06	1.85	56.	8
0.07	1.78	48.	8
0.08	1.71	41.	9
0.09	1.64	35.	9
0.10	1.58	30.	9
0.11	1.51	26.	9
0.12	1.45	22.	10
0.13	1.40	18.	10
0.14	1.34	15.	10
0.15	1.29	12.	11

COSTO ESPECIFICO DE CAPITAL 1.61
TASA INTERNA DE RETORNO 22.02

1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
10.79	10.86	11.87	11.87	11.87	11.87	11.87	11.95	11.95	11.95	11.95	11.95	11.94	12.03	12.03	12.03
10.79	10.86	11.87	11.87	11.87	11.87	11.87	11.95	11.95	11.95	11.94	11.95	11.94	12.03	·12.03	12.03
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1 05
21.71	29.38	37.54	46.77	56.00	65.21	74.39	83.55	92.73	101.87	110.98	120.07	129.13	138 16	147.23	156.28
33 55	41.29	50.46	69.69	68.92	78.13	87.31	96.55	105.73	114.87	123.98	133.07	142.12	151.24	160.31	169.36
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0.0
2.39	2.43	2.64	2.64	2.66	2.69	2.71	2.77	2.81	2.84	2.86	2.89	2.91	2 96	2.98	3 01
1 05	1.05	1.05	1.05	1.05	1.05	10.5	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
3 44	3.48	3.69	3.69	3.71	3.74	3.76	.3.82	3.86	3.89	3.91	3.94	3.96	4.01	4.03	4 06
0 73	0.27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0
0.0	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0
0.73	0.27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0
4.17	3.75	3.69	3.69	3.71	3.74	3.76	3.82	3.86	3.89	3.91	3.94	3.96	4.01	4.03	4 06
29 38	37.54	46.77	56.00	65.21	75.39	83.55	92.37	101.87	110.98	120.07	129.13	138.16	147.23	156.28	30

TABLA 7: RESUMEN DE RESULTADOS DE LA EVALUACION FINANCIERA

Con Estacionamiento	Con Deducción Predial	Con Terreno	Valor Medio Rentas	Alternativa. Número	Relación de B/C		Valor presente beneficios netos.		Año de recuperación.		Costo específico de capital.	Tasa interna de retorno.
					0.05	0.15	0.05	0.15	0.09	0.15		
NO		SI	PESIMISTA	1	1.37	0.83	25.	-8.	13	–	13.57	11.18
			MEDIO	2	1.56	0.96	40.	-2	11	–	13.85	14.15
			OPTIMISTA	3	1.51	0.98	37.	-1.	10	–	12.87	14.45
SI	SI	SI	PESIMISTA	4	1.32	0.82	25.	-9.	14	–	13.24	10.71
			MEDIO	5	1.49	0.93	40.	-4.	12	–	14.11	13.43
			OPTIMISTA	6	1.65	1.04	53.	2.	10	20	13.13	15.87
		NO	PESIMISTA	7	1.42	0.91	31.	-4.	12	–	14.12	12.86
			MEDIO	8	1.59	1.04	45.	2.	10	20	12.90	15.91
			OPTIMISTA	9	1.76	1.15	59.	7.	9	14	12.00	18.68
	NO	SI	PESIMISTA	10	1.37	0.84	28.	-8.	13	–	13.80	11.30
			MEDIO	11	1.54	0.96	42.	-2.	11	–	13.82	14.00
			OPTIMISTA	12	1.70	1.06	56.	3.	10	18	12.88	16.42
		NO	PESIMISTA	13	1.47	0.94	33.	-3.	12	–	13.77	13.55
			MEDIO	14	1.65	1.07	48.	3.	10	18	12.61	16.57
			OPTIMISTA	15	1.83	1.19	62.	9.	9	13	11.87	19.33

horizonte económico de análisis de 25 años, en un esquema tabular que se conoce en este tipo de estudios como cuadro de fuentes y usos de fondos. Las cifras que ahí aparecen están expresadas en miles de pesos; en la tabla 6-B aparece el análisis de sensibilidad para los 3 índices de evaluación que dependen de la tasa de actualización (relación B/C, valor presente de beneficios netos, y período de recuperación), así como los valores correspondientes de la tasa interna de retorno y costo específico de capital (único para un horizonte económico de análisis dado). En la parte inferior de esa tabla como se puede observar, la tasa de actualización se hizo variar del 1 al 15%.

Finalmente, en la tabla 7 se muestra la tabla de decisiones que esquematiza los resultados de las 15 alternativas estudiadas. En dicho cuadro se observa que los grupos 7, 8 y 9 y 14 y 15 son los que presentan una mayor rentabilidad atendiendo fundamentalmente a su tasa interna de retorno como a su diferencia con respecto al costo específico de capital, por otra parte la relación beneficio/costo y el valor presente de los beneficios netos, coinciden con esta apreciación, lo que implica, que ya sea que se deduzca o no el impuesto predial, la mejor solución es no considerar el costo de adquisición del terreno como parte del proyecto por financiar.

5. *Conclusiones.*

Sea como fuere, lo cierto es que la metodología que se acaba de presentar ha servido de base para evaluar alrededor de un 80% de los proyectos de infraestructura en los organismos internacionales de crédito, y existe una fuerte tendencia a intentar aplicar dicha metodología a la evaluación, con fines de otorgamiento de créditos, a los proyectos de beneficio social, tales como los proyectos educativos.

Es muy conveniente que las entidades responsables del desarrollo de proyectos educativos en la región, empiecen a capacitarse en el empleo de estas técnicas que podrán permitir a mediano plazo negociaciones más justas tanto con los organismos internacionales de crédito, como con los consejos superiores de planificación que dirigen las economías de nuestros países y con un mayor conocimiento de causa por parte de los responsables del proyecto.

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4. EL ENFOQUE DE SISTEMAS EN LA PROGRAMACION ARQUITECTONICA.

David Cymet

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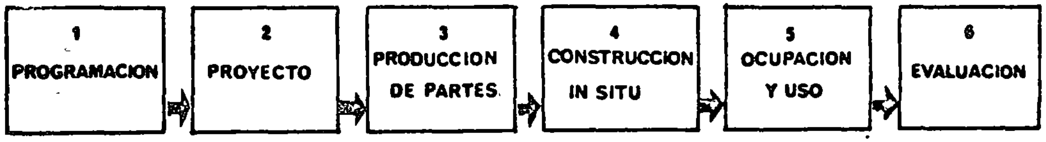
EL ENFOQUE DE SISTEMAS EN LA PROGRAMACION ARQUITECTONICA

DAVID CYMET L.

EL PROGRAMA ARQUITECTONICO Y LAS ESPECIFICACIONES DE PROYECTO

La etapa de programación es de importancia decisiva dentro del ciclo existencial total de todo edificio. El ciclo se inicia con la etapa de programación y se continúa con la de diseño, que sirve de base a la producción de partes y a la construcción, para finalmente culminar en la ocupación y uso. Esta etapa final de uso, a su vez, es el antecedente de la programación de edificios subsecuentes, pues permite confrontar las hipótesis del proyecto anterior con la realidad operante, haciendo evolucionar los nuevos programas.

Tradicionalmente la etapa de programación arquitectónica se ha reducido a obtener solamente la lista de los locales o espacios arquitectónicos por resolver, en base a las necesidades de espacio de los futuros usuarios del inmueble.



1. CICLO GENETICO DE LOS EDIFICIOS

de la cual forma parte integral la llamada ingeniería de sistemas. Surgida en otros campos del diseño, esta disciplina empieza a tener aplicación en el campo de la arquitectura al considerar que todo edificio es un sistema compuesto de varios subsistemas.

La concepción de la arquitectura como un sistema tiene profundas repercusiones en todo el proceso de gestación del producto arquitectónico, haciendo posible un acercamiento cada vez mayor entre las necesidades reales por satisfacer y el proyecto.

El objeto de aplicar las disciplinas antes citadas a los problemas arquitectónicos es el siguiente: crear un sistema de información capaz de captar las necesidades reales de los usuarios y de todos los sectores afectados por el futuro edificio, y de traducirlas en determinantes, o requerimientos de proyecto, es decir en especificaciones generales de proyecto por satisfacer en el mismo. Estas especificaciones de proyecto han de constituir asimismo el estándar de referencia para controlar y evaluar el proyecto, permitiendo comprobar su validez como satisfactor de las necesidades que lo motivaron.

El planteo anterior requiere que se esclarezca en este punto el significado de las citadas especificaciones de proyecto para diferenciarlas nítidamente de conceptos limítrofes tales como las especificaciones de construcción y las normas de diseño y producción.

Una norma de un producto genérico es una regla de carácter general a la que se han de someter todos los productos que pertenecen a ese género. Por definición una norma no se refiere a un objeto individual con-

Los proyectistas han reconocido universalmente que una programación así es absolutamente insuficiente para el logro de soluciones que respondan a las diversas necesidades reales de los usuarios, pues estos programas no tienden un puente de información entre las necesidades reales y la labor de proyecto. El divorcio entre estos dos aspectos se traduce en edificios que no guardan correspondencia con las condiciones reales en que va a existir y ser usado el edificio.

De ahí que en el campo de la arquitectura, así como en otros campos de diseño, haya surgido la convicción de que la etapa de programación debe de fructificar en algo mucho más completo y operante que un mero enlistamiento de locales. El proyectista necesita conocer en forma sistemática todas las exigencias que se han de satisfacer en su proyecto, tales como las condiciones de clima, luz, sonido, conservación, aislamiento, etcétera, que deben prevalecer en los espacios arquitectónicos que va a proyectar. Estas informaciones, entre otras, son tan necesarias en el programa arquitectónico como las listas de locales y las dimensiones.

De hecho el movimiento funcionalista moderno había ya planteado la necesidad de una programación que abarcara la totalidad de las necesidades humanas de los usuarios. Sin embargo tal pretención no pasaba de ser más que un mero enunciado teórico que estaba muy lejos todavía de tomar forma concreta.

Esta situación ha empezado a cambiar con el surgimiento de varias disciplinas nuevas, pero en especial gracias al de la ciencia de sistemas, creto, sino que reglamenta géneros o conjuntos de objetos. Una norma es el antecedente en el que se basan los diferentes proyectistas y realizadores de productos competidores que pertenecen al mismo género y a la cual todos deben satisfacer.

En cambio las especificaciones generales son prescripciones referidas a un problema particular concreto, en cuya solución han de ser respetadas. Representan la aplicación de la norma a un caso particular. Hay que hacer notar que el hecho esencial de que las especificaciones de proyecto estén ligadas a un problema particular real, de ninguna manera significa que también lo estén a una solución particular de ese problema, sino que, por lo contrario, son comunes a la totalidad de soluciones posibles de ese problema. Tanto las especificaciones de proyecto como las normas en que se apoyan, son anteriores a la solución particular. En un orden de generalidad descendente las normas son seguidas por las especificaciones de proyecto, éstos por el proyecto mismo, y éste por las especificaciones de producción y construcción que sirven de base a la realización material. Las especificaciones de producción y construcción se han de distinguir de las especificaciones de proyecto, pues mientras el objetivo de las primeras es el de ligar el proyecto con su realización material, el de las últimas es el de ligar el programa con el proyecto.

Para cada problema particular que se presenta hay que establecer un cuerpo de especificaciones de proyecto propias, como parte de su programa.

Esta tarea es posible realizarla con la adecuada economía de esfuerzo, cuando se han establecido con anterioridad las normas de ese problema genérico. El establecimiento de normas escapa ciertamente las posibilidades del proyectista particular, y corresponde a instituciones nacionales e internacionales.

El establecimiento de normas requiere que se clasifiquen genéricamente los problemas arquitectónicos, es decir, que la ilimitada cantidad de problemas particulares reales, con sus variantes individuales, sea reducida a pocos tipos genéricos para referir sus normas.

Además hay que clasificar estos géneros de edificios por ubicaciones climáticas genéricas. Esta clasificación se puede realizar con un número reducido de categorías y subcategorías, tales como edificios residenciales, escolares, hospitalarios, etcétera. La clasificación por ubicaciones climáticas tampoco es problemática, pues en el caso particular de la República una división en un máximo de cinco regiones es suficiente para los fines propuestos.

El establecimiento de la clasificación anterior por géneros de edificios y zonas climáticas, no va en exclusión de normas de mayor generalidad comunes a todos o a algunos de los géneros de edificios para todas o algunas de sus ubicaciones geográficas.

Al afrontar un problema real concreto las normas son el antecedente para plantear muchas de las especificaciones generales de proyecto del programa. La ubicación del problema y el género arquitectónico a que pertenece son las dos coordenadas que permiten localizar las normas que le corresponden; y que se han de traducir en las especificaciones de proyecto del problema. Estas a su vez, deben expresar la totalidad de exigencias que han de satisfacer las diferentes partes del edificio por proyectar. Cada especificación de proyecto debe estar referida a cierta parte específica del edificio. El análisis del edificio como un gran sistema compuesto de varios sistemas y subsistemas, proporciona el marco de referencia adecuado para dar a conocer cada especificación a aquella parte del edificio a que corresponde.

A continuación se esboza un análisis de los sistemas que componen a los edificios, sistemas que sirven como marco de referencia a las especificaciones de proyecto de cualquier problema particular que se presente.

En la ingeniería de sistemas se reconocen dos tipos genéricos de sistemas:

1. Sistemas de flujo o corriente.
2. Sistemas asociativos.

Los sistemas de flujo o corriente son aquellos que procesan alguna corriente de carácter material (agua, gas, aire), energética (electricidad, calor) o informativa (radio, televisión, teléfono, etcétera). Los sistemas asociativos, en cambio, no procesan una corriente identificable, sino que realizan un servicio al ser usados, aunque pueden contener como subsistema algún sistema de flujo. Un edificio y un coche, considerados como objetos globales, son ejemplos típicos de sistemas asociativos.

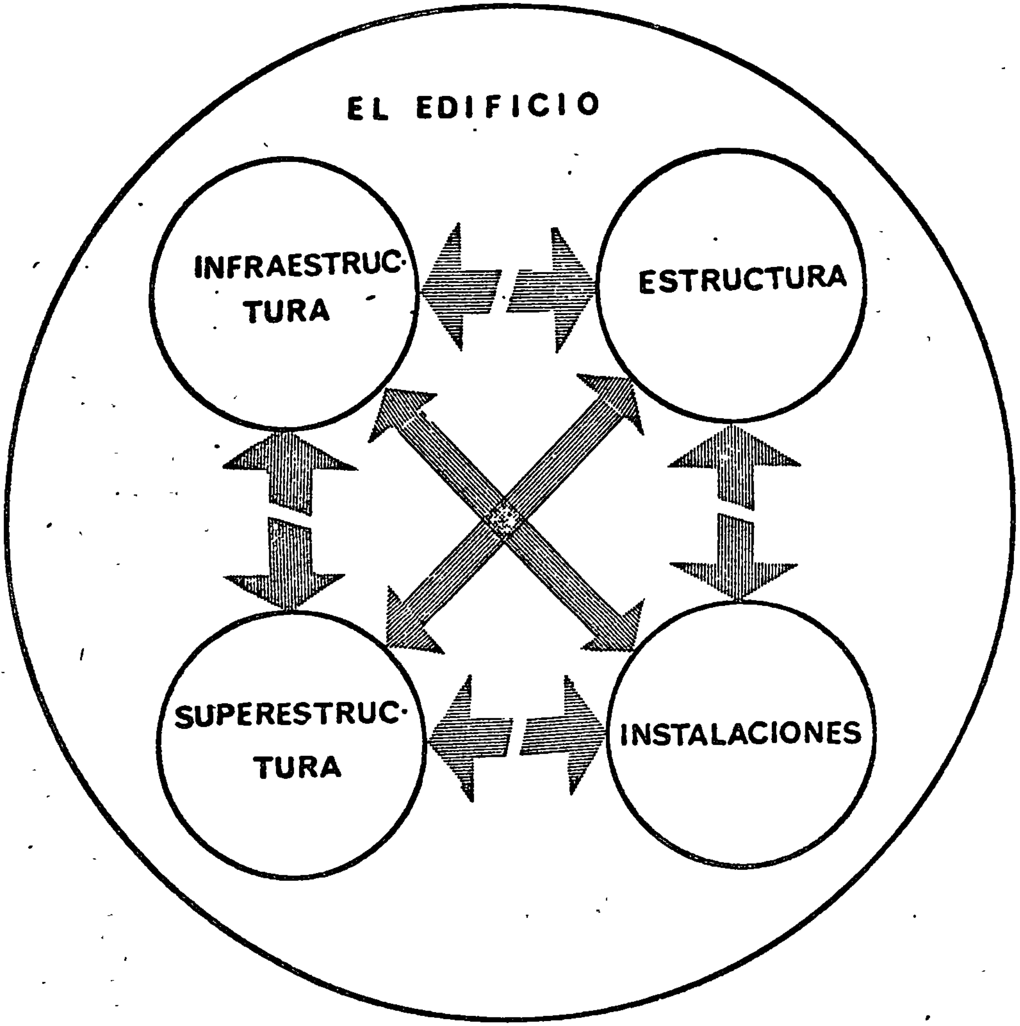
Al intentar identificar los géneros de sistemas que integran los edificios, se encuentra que éstos pertenecen a los dos tipos de sistemas citados, pues algunos conducen y procesan corrientes, como en el caso de las diversas instalaciones, mientras que otros cumplen una función de uso como sucede con el sistema de espacios arquitectónicos.

La identificación de los sistemas componentes de los edificios puede realizarse bajo dos puntos de vista diferentes, el funcional y el morfológico, que de ninguna manera deben de verse como mutuamente excluyentes, sino como complementarios.

Desde el punto de vista funcional todo edificio se compone de los cuatro géneros de sistemas siguientes:

1. Infraestructura.
2. Estructura.
3. Superestructura.
4. Instalaciones.

De estos cuatro sistemas componentes, sólo las instalaciones son del tipo de los sistemas de flujo, mientras que los restantes son sistemas asociativos.



2. EL EDIFICIO Y SUS SISTEMAS COMPONENTES DESDE EL PUNTO DE VISTA FUNCIONAL

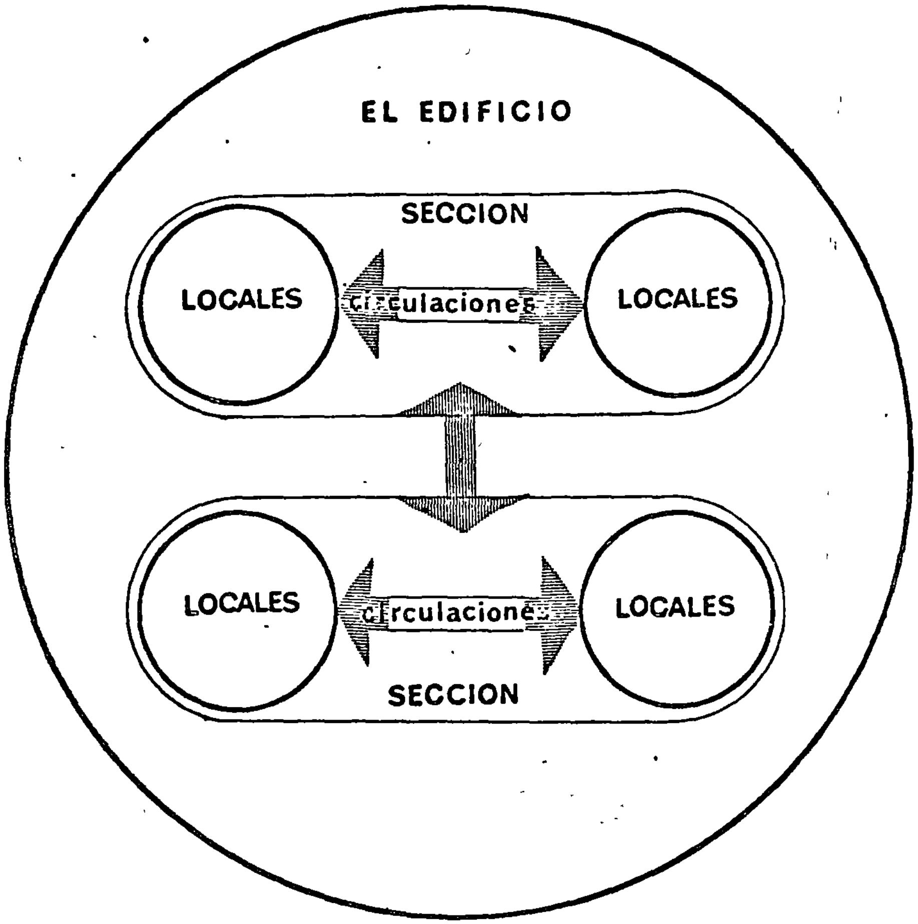
El primer sistema, la infraestructura, tiene como misión transmitir las cargas del edificio al subsuelo y se integra por los cimientos del edificio. La estructura es el sistema transmisor de cargas y la superestructura el sistema que subdivide el espacio. Finalmente, las instalaciones son los sistemas que conducen los flujos materiales, energéticos e informativos que requieren los ocupantes del edificio.

En cambio desde el punto de vista morfológico un edificio se desglosa en sistemas de espacios arquitectónicos de diversas jerarquías. Se trata en este caso de sistemas asociativos que tienen como función el ser ocupados y usados. Los sistemas de espacios arquitectónicos varían según el tipo de edificio. Por ejemplo, en el caso de los hospitales hay tres sistemas jerárquicos de espacios arquitectónicos que los componen:

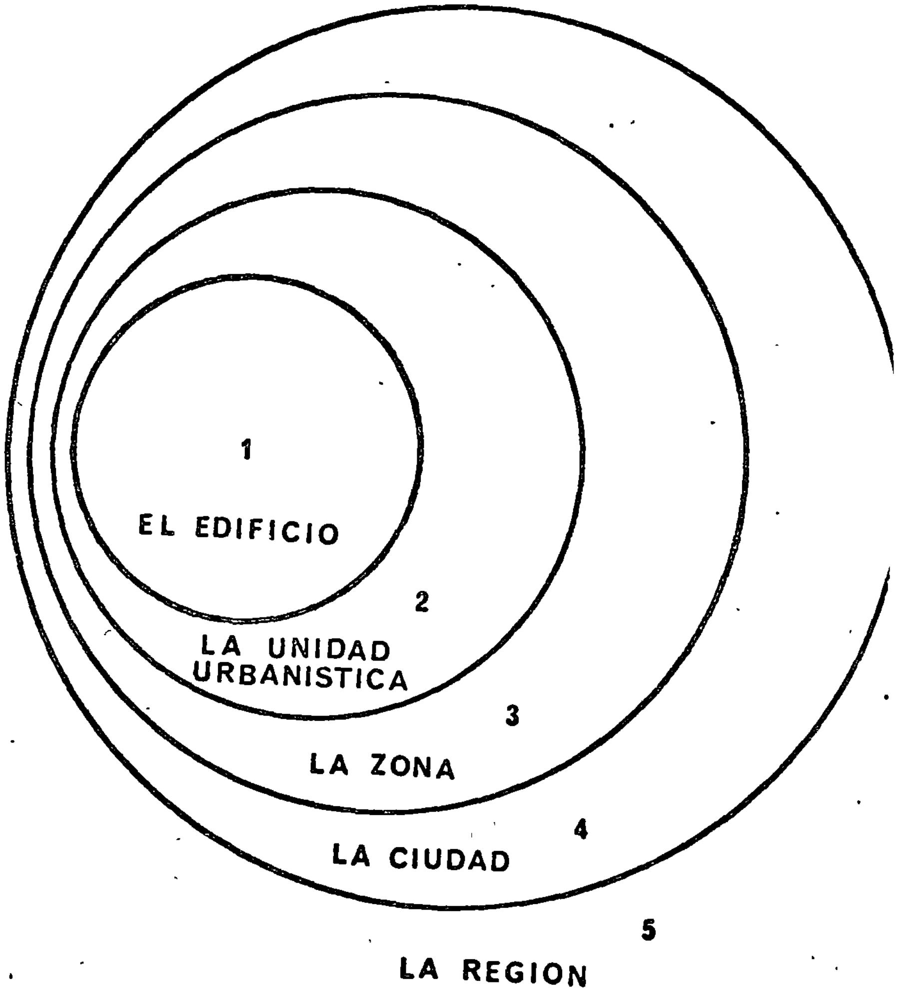
1. Locales y circulaciones.
2. Secciones (formadas por locales y circulaciones).
3. Servicios (integrados por secciones).

El edificio, que en sí es un conjunto de sistemas, a su vez forma parte de un sistema más amplio: el conjunto urbanístico, el cual asimismo pertenece a sistemas urbanos de rango superior de la ciudad.

Los sistemas de espacio no son meras abstracciones formales, sino que representan partes anatómicas reales del edificio, integradas a su vez por elementos de la superestructura, la estructura y las instalaciones. Todos estos elementos se conjugan para crear el espacio arquitectónico.



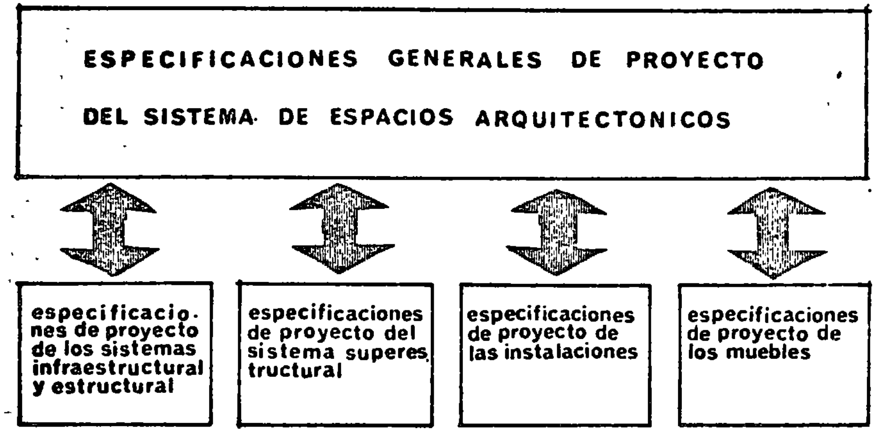
3. EL EDIFICIO Y SUS SISTEMAS DE ESPACIOS ARQUITECTONICOS DESDE EL PUNTO DE VISTA MORFOLOGICO



4. LOS SISTEMAS SUPERIORES DE LOS QUE FORMA PARTE EL EDIFICIO

Se trata pues de un desglose de los sistemas del edificio real, desde dos puntos de vista diferentes aunque no excluyentes.

Las especificaciones generales de proyecto se han de establecer en forma paralela tanto para los sistemas morfológicos como para los funcionales, pues las especificaciones de ambos tipos de sistemas son indispensables como antecedentes de cualquier solución o proyecto.



5. LAS ESPECIFICACIONES DE PROYECTO COMPLETAS DE UN EDIFICIO

Visto así, un programa completo de un problema arquitectónico no sólo debe contener la lista de elementos que integran su sistema espacial, como sucede en los programas arquitectónicos tradicionales, sino que además debe contener las especificaciones generales de proyecto de todos los sistemas restantes del edificio. Un programa completo permite que todos los diseñadores, arquitectos e ingenieros de las diversas especialidades que intervienen en el proyecto integral del edificio, tengan una auténtica base informativa en la cual puedan fundamentar las soluciones de los sistemas que les corresponden.

De todo lo anterior no debe sacarse la falsa conclusión de que la etapa de programación es en su totalidad anterior a la de proyecto. De hecho, se prolonga y llega a su fin hasta la terminación del proyecto mismo, pues este último influye en el programa modificándolo en el transcurso de su desarrollo. La programación es un proceso de aproximación sucesiva que mantiene una relación dialéctica con el proyecto.

Algo similar sucede con el proyecto, el cual no puede darse por terminado totalmente con anterioridad a la construcción, pues van surgiendo hechos que obligan a modificar el proyecto en el transcurso de la obra, alcanzando éste su forma definitiva solamente al terminar la construcción.

Las especificaciones generales de proyecto incluyen dos tipos:

1. Restricciones.
2. Criterios.

Las especificaciones completas de un problema deben incluir ambos tipos de especificaciones, ya que las restricciones sirven para comprobar la validez de las soluciones, y los criterios para medir su grado de optimidad.

Una solución, para poseer legítima validez como tal, debe primero satisfacer las restricciones del problema. Esto sin embargo no la convierte automáticamente en la solución óptima del problema, pues las restricciones las pueden satisfacer varias soluciones alternativas. Sólo cuando está de acuerdo –además– con los criterios establecidos, se puede hablar de la solución óptima del problema que satisface la totalidad de las especificaciones de proyecto.

En la elaboración de las especificaciones generales de proyecto de cualquier problema, hay que proceder a investigar y definir en primer término las restricciones y posteriormente los criterios.

Las restricciones que hay que definir son de dos tipos: externas e internas. Las externas se refieren a las entidades exteriores al sistema por proyectar que hay que tomar en cuenta en la solución, mientras que las internas se refieren a las características propias del sistema que se deben satisfacer en la solución.

Las restricciones internas de todo problema tienen su génesis en las externas, que representan el punto de arranque de la labor de especificación.

Los factores externos por considerar son los siguientes:

1. Actividades de uso del sistema.
2. Medio en que va a operar el sistema.
3. Recursos disponibles para realizar y operar el sistema.

Tanto para los sistemas asociativos como para los de flujo, estos factores proporcionan la fuente objetiva en que se genera el programa y sus especificaciones internas. Las especificaciones o restricciones internas de proyecto de un sistema son a su vez de tres tipos:

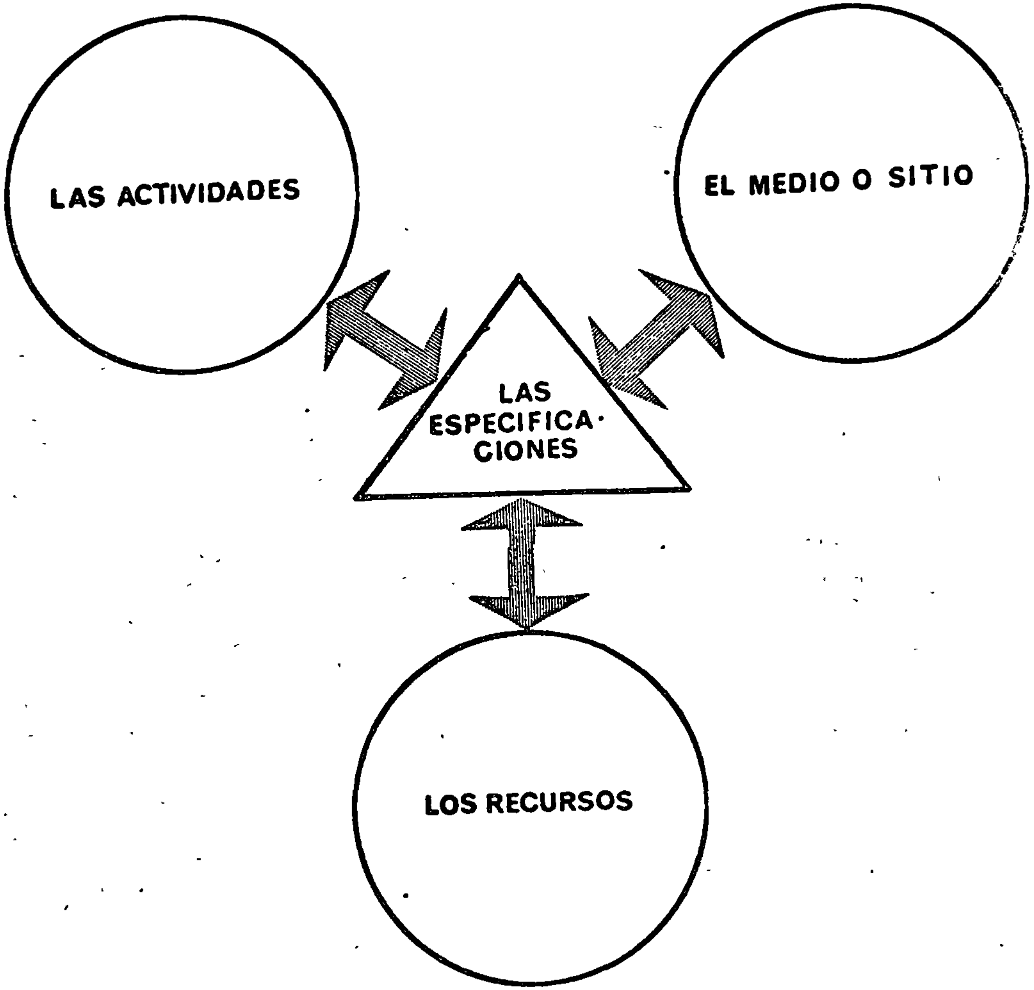
1. Especificaciones de funcionamiento del sistema (*performance specifications*).
2. Especificaciones materiales (*material specifications*).
3. Especificaciones de producción (*production specifications*).

A continuación se expondrá en forma particular para cada uno de los dos tipos de sistemas el significado de los factores externos y de las especificaciones.

1. *Los factores externos*

1.1. *Las actividades.* El análisis de las actividades para las que se crea un sistema asociativo, consiste en estudiar el uso a que este sistema estará sujeto.

Las actividades de uso del sistema son estudiadas analizando el proceso espacio-temporal en que se desenvuelve ese uso del sistema por los usuarios y sus diferentes objetos.



6. LOS FACTORES EXTERNOS QUE DETERMINAN LAS ESPECIFICACIONES DE PROYECTO

En el caso de las industrias y los diversos sistemas de trabajo, este proceso es estudiado por la ingeniería industrial.

La programación arquitectónica de todo edificio tiene su origen inicial en el análisis de las actividades de uso del edificio por proyectar. Se han de investigar las personas y objetos que intervendrán en el uso del futuro edificio, y el proceso de ese uso.

Como condición esencial para realizar el análisis de actividades, hay que identificar previamente el sector humano para el que se va a proyectar el sistema. En problemas pequeños este paso previo es tan obvio que pasa desapercibido; sin embargo, en problemas mayores constituye un paso explícito.

1.2. *El medio ambiente.* Las características físicas, culturales y estéticas del sitio en que va a operar o ser usado un sistema, influyen decisivamente en sus requisitos o especificaciones de proyecto. El análisis del sitio o medio ambiente tiene como fin adecuar el futuro sistema a las características del sitio.

En vía de ejemplo, la existencia de caminos rurales de naturaleza accidentada determina especificaciones de proyecto de un vehículo para transitar en ellos, diferentes a las que determinarían carreteras pavimentadas de alta velocidad.

En los problemas arquitectónicos, el análisis del medio ambiente consiste en estudiar las características del sitio en que se establecerá el edificio, definiendo las restricciones que éste impone al problema.

Este análisis puede iniciarse a un nivel de mayor generalidad cuando aún no se ha determinado el sitio exacto en que se ubicará el edificio, contando sólo con su macroubicación en una región o ciudad. Tal macroanálisis permite realizar una selección de los sitios disponibles, escogiendo el que mejor satisface las especificaciones referentes al sitio.

Una vez realizada esta selección se puede proceder a realizar el microanálisis del terreno escogido, para determinar las restricciones que impone al futuro proyecto, es decir, las especificaciones de proyecto que de él emanan.

1.3. *Los recursos.* Los recursos disponibles en un momento dado para realizar un sistema, no sólo determinan la posibilidad misma de realizarlo, sino que ejercen una influencia restrictiva sobre sus diferentes características, lo cual se ha de expresar por medio de especificaciones de proyecto.

Este factor no sólo abarca los medios financieros disponibles, sino que se refiere también a los diferentes medios de producción (humanos, materiales y tecnológicos) que entran en juego.

La realización de los análisis de los tres factores, actividades, sitio y recursos, permite definir las especificaciones de proyecto del sistema.

Las especificaciones ya expresan en forma directa e inmediata la información que se requiere para proyectar el sistema, pues traducen las restricciones que imponen las actividades, el sitio y los recursos en términos de características propias del sistema, que se han de satisfacer en su proyecto.

Se presenta a continuación una explicación somera del significado de los tres tipos de especificaciones, funcionamiento, materiales y producción, antes de proceder a analizar el proceso dialéctico que permite deducir las especificaciones de los factores externos.

1.4. *Las especificaciones de funcionamiento.* Las especificaciones de funcionamiento (*performance specifications*) expresan las diversas características de funcionamiento que ha de satisfacer el sistema por proyectar.

Estas características expresadas como requerimientos independientes uno del otro, se constituyen en la guía y prueba de validez del proyecto, y se fusionan en un todo en el proyecto que las satisface.

En los problemas arquitectónicos las especificaciones de funcionamiento abarcan no sólo el tradicional programa de partes y el diagrama de funcionamiento, sino que definen además las condiciones ambientales en ellos requeridos, tanto de índole visual como acústica, climática, mecánica, etcétera.

Esta información se deriva básicamente del conocimiento de las actividades y del medio ambiente, que son los dos factores externos básicos que determinan, junto con los recursos disponibles, el contenido completo del programa.

1.5. *Las especificaciones materiales.* La gama de materiales admisibles para la realización de un sistema está limitado por los requisitos que imponen las especificaciones de funcionamiento y por las restricciones que imponen las disponibilidades de recursos.

La determinación de las especificaciones materiales le proporciona al proyectista un claro conocimiento de los materiales de que puede disponer, y entre los cuales ha de realizar su selección final en el momento de proyectar.

Existen casos extremos en que la especificación material llega a la prescripción rígida de un material particular, en aquellas situaciones en que sólo un material determinado es capaz de satisfacer las especificaciones de funcionamiento y los factores externos.

En cambio hay situaciones en que sólo conviene definir las especificaciones de funcionamiento sin ocuparse de restringir los materiales, en aquellos casos en que es aconsejable conservar un alto grado de libertad creativa y económica. En tales casos casi no se establecen especificaciones materiales de proyecto.

Conviene advertir contra el peligro de confundir las especificaciones materiales de proyecto aquí citadas, las cuales son previas al proyecto, con las especificaciones materiales del proyecto ya resuelto, y que forman parte de la solución y no de la programación.

1.6. *Las especificaciones de producción.* Las especificaciones de producción restringen los procedimientos de ejecución material admisibles en la solución del sistema.

Esta restricción puede tener su origen en los recursos, es decir en las posibilidades industriales, técnicas o económicas del problema.

En el caso de los problemas arquitectónicos las especificaciones de producción abarcan tanto el aspecto de los procedimientos productivos admisibles en la producción de partes fabricadas industrialmente, tales como ventanas, puertas, closets, etcétera, así como los procedimientos constructivos que pueden utilizarse en la construcción del edificio *in situ.*

Una vez que se ha expuesto el significado de los factores externos y de las diversas especificaciones de los sistemas de tipo asociativo, corresponde aclarar la metodología a seguir en su definición.

El punto de partida en la definición de las especificaciones de proyecto radica en el análisis de actividades. El sistema por proyectar se hace para realizar esas actividades de uso. En el caso de los edificios, es decir de los sistemas arquitectónicos, éstos se crean para albergar las actividades que en ellos se van a ejecutar. El analizar las actividades que el edificio ha de albergar, permite establecer los espacios necesarios para tal fin y las diversas características ambientales y funcionales de esos espacios. En otras palabras, el conocimiento de las actividades permite definir el programa de espacios, así como las especificaciones de funcionamiento de los mismos.

Como ya se ha mencionado, el análisis de actividades no puede ser realizado en forma atemporal y aespacial, sino que requiere una ubicación de tipo macrogeográfico e histórico, pero sin necesidad de conocer en esta etapa la microubicación del futuro edificio o sistema.

El programa de necesidades deducido de las actividades no es sin embargo el definitivo, pues al no haber pasado por el tamiz de los recursos disponibles, expresa solamente necesidades y no posibilidades. Asimismo no incluye todavía el amplio sector de especificaciones que tienen su origen en la naturaleza física y cultural del terreno o sitio en que va a estar el edificio. De ahí que una vez que se ha llegado a definir el primer programa teórico, se proceda a evaluar los recursos disponibles para su realización, modificando el programa en función de las posibilidades de capital, materiales, personal, etcétera. Se llega en esa forma a un programa realista que no expresa carencias abstractas, sino carencias cuya satisfacción está dentro de los límites de lo posible.

Se procede entonces a realizar la selección del sitio, en base a los requerimientos o especificaciones del programa, escogiendo aquel que mejor satisfaga las experiencias en él expresadas. No siempre, sin embargo, existe la posibilidad o necesidad de realizar una selección: en aquellas situaciones en que el sitio está ya predeterminado. En cualquiera de ambos casos se procede entonces al análisis del sitio, tanto desde el punto de vista físico como cultural y estético.

El análisis del sitio implica tomar en consideración los factores siguientes:

1. *Características naturales del sitio*
    - 1.1 Topografía.
    - 1.2 Hidrografía (lagos, ríos, drenado natural).
    - 1.3 Suelos.
    - 1.4 Subsuelo.
    - 1.5 Flora.
    - 1.6 Clima.
2. *Características culturales del sitio*
    - 2.1 Ligas viales y tráfico.
    - 2.2 Uso del suelo.
    - 2.3 Valores del suelo y propiedad.
    - 2.4 Redes.
    - 2.5 Edificios y monumentos.
    - 2.6 Ambiente (ruidos, olores, contaminación atmosférica, etcétera).
3. *Características estéticas del sitio*
    - 3.1 Paisaje y vistas.
    - 3.2 Estilo y unidad con el medio urbanístico-arquitectónico.

El análisis del sitio puede modificar el programa de partes y las especificaciones ya alcanzadas, además de adicionar toda una serie de especificaciones de proyecto que tienen su origen en la confrontación del sitio con el programa.

El análisis del sitio se realiza en función de una hipótesis de programa, y consiste en confrontar las exigencias del programa tentativo con las posibilidades del sitio, sin llegar todavía a soluciones, investigando las restricciones que éste impone a la solución. En la misma forma se realiza la confrontación dialéctica entre los recursos y el programa, pues no tiene sentido alguno calcular recursos *per se*, sin referencia al objeto para el cual se requieren.

Por lo que respecta a los sistemas de flujo, hay necesidad únicamente de resaltar las diferencias existentes en el análisis de los factores externos, pues por lo que respecta a los géneros de especificaciones por definir, ambos tipos de sistemas coinciden totalmente.

En el caso de los sistemas o redes de flujo, el análisis de actividades y del sitio debe permitir llegar a definir las especificaciones de funcionamiento del sistema, las cuales se refieren a los dos aspectos siguientes:

1. Insumos o flujos alimentadores del sistema.
2. Productos del sistema.

El análisis de las actividades de los beneficiarios del sistema, en aquellos aspectos que tienen relación con él, y el análisis del sitio en que se ubicará la red, permiten conocer las características cuantitativas y cualitativas de los ingresos (insumos) materiales, energéticos o informativos de la red, y del producto que la red ha de entregar ya procesado en sus terminales de salida.

El problema de una red de agua es un buen ejemplo para ilustrar el procedimiento de programación. El conocimiento del sitio es necesario para conocer las características de la corriente de agua que alimentará la red, es decir el insumo material de la red, mientras que el análisis de las actividades de los beneficiarios de la red permite determinar las demandas de agua que hay que satisfacer, es decir el producto que ha de entregar la red.

Los análisis de actividades y del sitio permiten también definir las condiciones de trabajo y desgaste que se originan en el medio ambiente y en el uso humano, y que la red ha de ser capaz de resistir en determinada medida, lo cual se ha de expresar también en las especificaciones de funcionamiento de la red. Si en el ejemplo citado el análisis del sitio revela que la red se ubicará en un lugar con un alto contenido de salinidad ambiental, este hecho determina una especificación de funcionamiento relativa a las características anticorrosivas deseables de la futura red.

Las especificaciones de funcionamiento y el análisis de recursos son a su vez los dos antecedentes más importantes para definir las especificaciones de proyecto de materiales y producción.

El conocimiento de los recursos materiales y productivos del sitio permite definir la gama de materiales y procedimientos con los que se puede contar en principio en la solución, para satisfacer las exigencias expresadas en las especificaciones de funcionamiento.

En los problemas arquitectónicos hay que afrontar ambos tipos de sistemas, los asociativos y los de flujo. Mientras que el edificio global, así como sus conjuntos de espacios, su estructura, infraestructura y superestructura representan sistemas asociativos, las diferentes instalaciones o redes son todos sistemas de flujo.

La labor de programación debe abarcar todos y cada uno de los sistemas del problema arquitectónico, para lo cual se hace aquí un examen individual de cada uno de estos sistemas y subsistemas, desde el punto de vista de sus especificaciones de proyecto.

Hay que destacar que en todo problema arquitectónico los diferentes sistemas componentes no son autónomos, sino que forman parte de un sistema que los engloba: el edificio. Dicho en otras palabras, relativamente al edificio todos los demás sistemas son sólo subsistemas. Esto significa que el objetivo de optimización vale para el edificio como un todo, mientras que por lo que respecta a los diferentes subsistemas a lo sumo se puede tender a su suboptimización. La programación o especificación de los subsistemas del edificio está subordinada, por consiguiente, a la del edificio.

Empezando por el sistema de espacios arquitectónicos, se expone a continuación, para cada uno de los sistemas que constituyen un edificio, cuáles son los aspectos que se deben definir en sus correspondientes especificaciones de proyecto, así como la relación que hay entre éstas y los factores externos que las generan.

A. *El sistema de espacios.* Este sistema está constituido por los diferentes espacios de un edificio, entre los que se incluyen también los espacios destinados a las circulaciones. Programar este sistema significa definir las siguientes especificaciones de proyecto:

- A.1 Espacios requeridos.
- A.2 Dimensiones de estos espacios.
- A.3 Restricciones de su forma geométrica.
- A.4 Ligas entre los espacios.
- A.5 Condiciones ambientales de los espacios:
  - A.5.1 Climáticos.
  - A.5.2 Lumínicos.
  - A.5.3 Acústicos.
  - A.5.4 Vistas.
- A.6 Condiciones de seguridad requeridas.
- A.7 Condiciones estéticas.
  - A.7.1 Colores.
  - A.7.2 Texturas, etcétera.

Este enlistamiento no pretende ser exhaustivo, aunque abarca de hecho los aspectos más relevantes por considerar al programar el sistema de espacios arquitectónicos.

El proceso para determinar las especificaciones del sistema de espacios arquitectónicos, requiere la realización del análisis de los tres factores externos: actividades, sitio y recursos.

El análisis de actividades, generalmente el primero en realizarse por su carácter primario, se refiere a los aspectos siguientes:

a) Número de ocupantes de los espacios, clasificados por tipos.
b) Número de objetos de moblaje, almacenamiento, uso y consumo que se albergarán en esos espacios, clasificados por tipos.
c) Procesos espacio-temporales de ocupación y uso de los espacios por los ocupantes y sus objetos.

El análisis de las actividades en los términos de personas, objetos y procesos ofrece la base para proponer tentativamente la primera hipótesis de programa y especificaciones de proyecto, la cual se sujetará a modificaciones iterativas en los análisis subsecuentes del sitio y de los recursos disponibles.

Es importante hacer notar que para muchas de las especificaciones no hay necesidad de analizar individualmente cada actividad, sino que basta referirse a grupos enteros de actividades (por ejemplo: actividades administrativas, médicas, etcétera) que determinan una misma especificación común. En esta forma hay un gran ahorro de esfuerzo en la labor de especificación.

Al realizar el análisis de actividades en los términos anteriores, se trabaja inclusive con el grupo que abarca la totalidad de las actividades, o una amplia fracción de las mismas. En vía de ejemplo se puede citar que la mayoría de las especificaciones de higiene requeridas en la solución de un hospital, se pueden obtener refiriéndose a la totalidad de actividades hospitalarias, sin necesidad de recurrir a su análisis individual.

La hipótesis de programa que resulta del análisis de actividades, permite proceder a realizar la selección del sitio más adecuado para ubicar el edificio al ofrecer un patrón de necesidades. Cuando el sitio ha sido ya predeterminado, este paso no es necesario, procediéndose al análisis del sitio dado.

El análisis del sitio permite avanzar más en la definición del programa y sus especificaciones, pues las características del terreno influyen en las mismas. Si el sitio por ejemplo padece molestias por ruidos aledaños, este hecho determina una especificación de proyecto en la que se expresa la necesidad de protegerse contra esos ruidos.

En rigor, la finalidad de analizar las características del sitio con relación al programa, no es otra que la de llegar a definir todas las restricciones que impone el terreno al problema, antes de proceder a proyectar.

Ya se indicó con anterioridad, al hablar de los sistemas arquitectónicos en general, cuáles eran los diversos puntos que se han de investigar al realizar el análisis del sitio, por lo cual no hay necesidad de repetir la misma lista.

Después del análisis del sitio se ha de proceder a realizar el análisis de recursos, que consiste en confrontar los recursos disponibles con los tentativamente necesarios para realizar el programa hipotético. Esta confrontación permite ajustar el programa a la realidad, expresando no únicamente lo que es deseable, sino también lo que es posible. Este análisis se refiere no sólo a los recursos monetarios, sino también a los diferentes recursos de naturaleza no financiera requeridos para realizar el programa. Un programa se ha de modificar no sólo por la insuficiencia de recursos monetarios, sino también por la carencia de determinados materiales, técnicas o mano de obra.

El análisis de recursos es por consiguiente una etapa muy importante en el proceso de gestación del programa, pues los recursos disponibles determinan el programa en la misma forma que las actividades y las características del sitio. En términos generales los recursos que hay que considerar son los siguientes:

- 1.2.1. Recursos monetarios.
- 1.2.2. Recursos de producción.
    - 1.2.21 Materiales.
    - 1.2.22 Mano de obra.
    - 1.2.23 Técnicas.

Una vez que el programa inicial ha pasado por el cedazo de los recursos y se ha ajustado en función de éstos, se procede al ajuste final del programa y de sus especificaciones de proyecto. Este programa ya es el antecedente inmediato del proyecto arquitectónico.

B. *Las instalaciones.* Las instalaciones o redes de los edificios son sistemas de flujo que se han de especificar como corresponde a este tipo de sistemas, en que el análisis de actividades y del sitio debe estar dirigido a definir en primer término los insumos y productos como parte fundamental de sus especificaciones de funcionamiento.

Las instalaciones son todos sistemas de flujo que poseen entradas en que ingresa su insumo, y terminales en que emerge el producto procesado. En las instalaciones de los edificios existen los tres tipos de sistemas de flujo, tanto de corriente material, como energética e informativa. Se presenta una lista de los tipos más comunes de instalaciones:

- B.1 Instalaciones de corriente material.
    - B.11 Agua fría.
    - B.12 Agua caliente.
    - B.13 Oxígeno.
    - B.14 Aire acondicionado.
    - B.15 Gas.
    - B.16 Petróleo.
    - B.17 Diesel.
    - B.18 Desagüe y drenaje.
    - B.19 Desalojo de basuras.
    - B.20 Aire comprimido.
- B.2 Instalaciones de corriente energética.
    - B.21 Electricidad.
    - B.22 Iluminación.
    - B.23 Calor.

- B.24 Rayos X.
- B.25 Refrigeración.

B.3 Instalaciones de corriente informativa.

- B.31 Teléfono.
- B.32 Radio.
- B.33 Televisión.
- B.34 Sonido.

Las especificaciones de proyecto de estas redes deben definir los aspectos siguientes:

A.1 Especificaciones de funcionamiento.

- A.11 Terminales de insumo y de producto requeridas.
- A.12 Volúmenes del insumo y del producto.
- A.13 Características cualitativas del insumo y del producto.
- A.14 Registrabilidad de la red.
- A.15 Exigencias de seguridad.
- A.16 Exigencias estéticas.

A. 2 Especificaciones materiales.

- A.21 Materiales admisibles en la solución.
- A.22 Materiales inadmisibles en la solución.

A.3 Especificaciones de producción.

- A.31 Procedimientos de producción admisibles en la solución.
- A.32 Procedimientos de producción inadmisibles en la solución.

Para definir estas especificaciones hay necesidad de recurrir al análisis dirigido de los factores externos, es decir de las actividades, el sitio y los recursos.

Las diversas actividades por desempeñar en el edificio generan una determinada demanda de corrientes materiales, energéticas e informativas, así como una oferta como en el caso de las diferentes corrientes de deshechos materiales. En el primer caso las demandas definen el producto de las redes, y en el segundo caso esos deshechos se convierten en los insumos de las redes de desalojamiento de desperdicios. Las llamadas que tienen su origen en el interior del edificio, son igualmente insumos de la red.

Esto significa que las actividades permiten calcular el producto que debe ser capaz de proporcionar la red para su desempeño, y de definir sus características cualitativas. Asimismo permiten definir los insumos de aquellas otras redes que en el edificio tienen como misión básica recoger y desalojar insumos.

Para especificar el volumen y características del agua de la red de agua de un edificio, por ejemplo, se recurre a determinar las demandas de este líquido que generan las diferentes actividades. En cambio para una red de aguas negras, las actividades en el edificio permiten calcular los volúmenes de aguas negras por desalojar, es decir, los insumos de esa red.

Es conveniente hacer notar que este método de especificación vale igualmente para las redes de flujo informativo, pues los volúmenes de información que la red debe entregar o recoger está en función directa de los ocupantes y sus actividades. Los volúmenes de información se miden actualmente con la misma precisión que los gastos materiales en unidades tales como *bits*, número de llamadas, etcétera.

Por lo que respecta a las redes cuyos insumos se originan externamente al edificio, hay que recurrir al análisis del sitio para su determinación. El insumo de la red de agua se conoce a través de las características del diámetro, gasto y presión de la toma domiciliaria, datos que proporciona la investigación del sitio inmediato o de la zona.

La definición adecuada de los insumos y productos de una red, cuyo cálculo requiere muchas veces de procedimientos estadísticos, permite que la solución subsecuente de ésta resulte en una red sin congestionamientos, capaz de responder a las demandas reales de servicio.

Una vez que se han definido el insumo y el producto, se puede proceder a definir las especificaciones de funcionamiento restantes, tales como que la red sea registrable, subterránea, aparente, etcétera. En esta tarea hay que recurrir no sólo al análisis de actividades y del sitio, sino también a los recursos disponibles para la red.

Subsecuentemente, en base a las especificaciones de funcionamiento, así como a las actividades, el sitio y los recursos, se pueden establecer los materiales admisibles e inadmisibles para la solución de la red, y los procedimientos de producción y construcción, es decir, las especificaciones de proyecto de los materiales y la producción.

C. *El sistema superestructural.* El sistema superestructural abarca los diferentes acabados de un edificio, que se sobreponen al sistema estructural. Este sistema es un conjunto de subsistemas, entre los cuales se cuentan los siguientes:

1. Ventanas.
2. Plafones.
3. Pisos.
4. Muros y divisiones.
5. Puertas.

Cada sistema superestructural es un compuesto de diferentes elementos que el diseñador integra en un sistema coherente. Esto significa que no se trata meramente de materiales aislados, sino de compuestos de materiales cuya composición es resuelta por el diseñador.

El diseñador de los sistemas de acabados requiere, como en el caso del diseño de cualquier otro sistema, de especificaciones de proyecto que le permitan responder a los requerimientos de los usuarios, en un medio ambiente determinado, con los recursos disponibles.

Los sistemas de acabados son todos de tipo asociativo, Para realizar su especificación se aprovecha el marco de referencia que ofrece la hipótesis de programa, debiéndose determinar los requerimientos que corresponden a los acabados de cada uno de los espacios arquitectónicos.

Las especificaciones de proyecto de los sistemas de acabados tienen su génesis en el análisis de las actividades que se realizaran en los diferentes espacios del edificio, en las condiciones del sitio y en los recursos disponibles.

Estos factores representan los hechos objetivos de los que emanan las especificaciones de proyecto de los acabados.

En vía de ejemplo, las actividades de los usuarios relacionadas de alguna manera con la ventanería de un edificio, así como las condiciones climáticas, acústicas y visuales del sitio determinan los requerimientos que este sistema debe satisfacer. Si las actividades por desempeñar requieren silencio, y las condiciones del sitio son ruidosas, la ventanería deberá ser aislante de ruido en esa medida. Si estas mismas actividades requieren un ambiente de vistas exteriores y el sitio ofrece algunas muy agradables, el sistema de ventanería deberá especificarse de antemano para captar estas vistas. En forma similar deberá procederse con las demás relaciones que se establecen entre las actividades, el sitio y el sistema satisfactor.

Este procedimiento debe realizarse sistemáticamente para cada uno de los sistemas superestructurales. Así por ejemplo, si se procede a definir las especificaciones de proyecto del sistema de acabados de los pisos, se necesita analizar las actividades de cada local. Si un determinado espacio estará dedicado a las actividades de aseo personal, estas actividades determinan especificaciones de funcionamiento (*performance specifications*) del piso, tales como que éste sea antiderrapante y térmico para que no se resbalen o resfríen las personas, resistente al ataque de agua, detergentes y desechos, lavable e impermeable.

Las especificaciones de funcionamiento sirven a su vez de base al establecimiento de las especificaciones de proyecto materiales y de producción, admitiendo o vedando la posibilidad de determinados materiales y sistemas de producción. En esta etapa interviene fuertemente el análisis de recursos, pues depende de la disponibilidad de recursos el que se restrinja la gama de posibilidades de materiales y procedimientos de producción y construcción.

Las especificaciones de proyecto de los diversos sistemas superestructurales deben definir los aspectos siguientes:

- C.1 Especificaciones de funcionamiento.
  - C.11 Restricciones geométricas.
    - C.111 Dimensionales.
    - C.112 Formales.
  - C.12 Restricciones físico-químicas.
    - C.121 Mecánicas.
    - C.122 Acústicas.
    - C.123 Térmicas.
    - C.124 Opticas.
    - C.125 Electromagnéticas.
    - C.126 Químicas.
  - C.13 Restricciones estéticas.
    - C.131 Colores.
    - C.132 Texturas.

- C.2 Especificaciones materiales.
  - C.21 Materiales admisibles.
  - C.22 Materiales inadmisibles.
- C.3 Especificaciones de producción.
  - C.31 Procedimientos admisibles.
  - C.32 Procedimientos inadmisibles.

Para ilustrar el significado de estos aspectos que se han de abarcar en la especificación de los sistemas superestructurales, se puede considerar el caso de las especificaciones de proyecto de las puertas de la sección quirúrgica de un hospital.

Si las puertas han de servir para actividades tales como el paso apresurado del personal y de camillas, y para aislar mecánica, óptica, acústica y biológicamente los locales en que se realizan las actividades quirúrgicas, se infieren de esos hechos las restricciones dimensionales y geométricas de las puertas, así como sus restricciones físicas, químicas, estéticas y de seguridad, definiendo subsecuentemente la gama de materiales y procedimientos productivos admisibles en el diseño de ese sistema de puertas.

D. *El sistema estructural e infraestructural.* El sistema estructural tiene como función básica resistir las cargas del edificio y canalizarlas al sistema infraestructural, es decir a la cimentación, el cual a su vez los transmite al subsuelo.

Estos dos sistemas, íntimamente relacionados, son de tipo asociativo. Para ambos sistemas es sumamente ventajoso definir especificaciones de proyecto antes de proceder a su solución.

Conviene aclarar que estas especificaciones se pueden elaborar en gran parte tan pronto como se han definido las especificaciones de proyecto del sistema de espacios, aunque hay que admitir que cierta fracción de los mismos sólo puede definirse subsecuentemente al iniciarse la solución arquitectónica del sistema de espacios.

Las especificaciones de proyecto de la estructura e infraestructura, deben definir los aspectos siguientes:

- D.1 Especificaciones de funcionamiento.
  - D.11 Restricciones geométricas.
    - D.111 Dimensionales.
    - D.112 Formales.
  - D.12 Restricciones mecánicas.
    - D.121 Cargas vivas permanentes.
    - D.122 Cargas vivas accidentales (viento, sismo).
    - D.123 Cargas muertas.
    - D.124 Características del suelo.
  - D.13 Restricciones estéticas.
- D.2 Especificaciones materiales.
  - D.21 Materiales admisibles en la solución de la estructura.
  - D.22 Materiales inadmisibles en la solución de la estructura.
- D.3 Especificaciones de producción.

D.31 Procedimientos de construcción y producción admisibles.

D.32 Procedimientos de construcción y producción inadmisibles.

Corresponde definir, en las especificaciones materiales, si es admisible o no intentar una solución en concreto armado o madera, por ejemplo. Asimismo se define en las especificaciones de producción la admisibilidad de buscar soluciones que impliquen procedimientos de prefabricación o de realización *in situ* de la estructura.

Para la definición de todas estas especificaciones de proyecto de la estructura y la cimentación, hay que remontarse, como en el caso de los demás sistemas, al análisis de las actividades, el sitio y los recursos. Las cargas vivas permanentes, por ejemplo, se definen en función de las actividades, mientras que las cargas vivas accidentales de sismo y viento, así como la resistencia del terreno, se determinan en función del sitio.

Las actividades determinan también, en gran medida, las restricciones dimensionales de la estructura, ya que los claros y alturas de la estructura no deben interferir con las actividades. También los recursos intervienen en la definición de las restricciones dimensionales y materiales, una vez que se han determinado los claros mínimos aceptables para las actividades.

Tradicionalmente se ha definido la gran mayoría de las especificaciones de proyecto de las estructuras en la etapa tardía de la solución y el diseño. No hay razón alguna para que la labor de especificación se realice tan tardíamente y en una forma casi implícita, impidiendo tener una noción clara y coherente del problema estructural antes de proceder a su solución particular, dentro del marco general del conjunto de sistemas que integran el edificio. La especificación de los sistemas estructural e infraestructural puede iniciarse tempranamente en el proceso de programación del problema arquitectónico, y culminar en sus aspectos fundamentales antes de proceder al proyecto y diseño de la estructura y cimentación.

E. *El sistema de los muebles.* En rigor los muebles no forman parte de los edificios. Su propio nombre denota que son objetos móviles, que no están físicamente unidos a la construcción. Sin embargo, si se toma en consideración que éstos permanecen constantemente en el edificio como si fueran parte del mismo, y que guardan una íntima relación funcional con él, se comprende la necesidad de que la programación de todo problema arquitectónico abarque también el conjunto de muebles, que forma un sistema propio.

El procedimiento de programación de los muebles no es diferente, en principio, al de los demás sistemas de un problema arquitectónico. Para definir las restricciones de los muebles hay que remontarse a las actividades que se han de desempeñar con estos objetos. El análisis de actividades se ha de completar con la investigación de los factores del sitio, para integrar el conjunto total de las restricciones. El sistema de espacios arquitectónicos proporciona un adecuado marco de referencia para realizar la investigación en forma sistemática.

Como ejemplo se presentan a continuación las restricciones, que corresponden a un problema hospitalario hipotético, a los mostradores para atender al público.

La investigación de actividades por desempeñar en el mostrador citado, ha de permitir conocer el número máximo de personas del público por atender ahí simultáneamente, el número de empleados que realizarán tal actividad, los diversos objetos instrumentales requeridos, tales como teléfonos, interfonos, máquinas de escribir, kárdex, los volúmenes y tipos de documentación que se usarán, así como la forma en que se desenvuelve el proceso de atención al público.

Este conjunto de datos relativos a las actividades que se desempeñan en el mueble, sirve de base para elaborar subsecuentemente las especificaciones de proyecto del funcionamiento, materiales y producción.

LOS CRITERIOS

El planteo de las restricciones de un problema arquitectónico no es suficiente para su determinación completa. Se requiere que se definan, además, los criterios que han de regir la solución y que han de permitir optar por la mejor entre varias soluciones, pues mientras que las restricciones permiten comprobar la validez de las soluciones, los criterios no impiden comparar su mérito relativo.

Una solución de un sistema sólo puede estar en dos condiciones posibles respecto a una restricción: la satisface o no. En cambio desde el punto de vista de los criterios, una solución se distingue de otra por el grado relativo en que posee las cualidades que se enuncian en esos criterios. Por consiguiente, para determinar plenamente un problema y poder optar racionalmente por alguna de las soluciones posibles, hay necesidad de recurrir a los criterios que han de normar la solución.

Los criterios más importantes que norman la solución de los diferentes sistemas de un problema arquitectónico se enuncian a continuación en forma general, requiriéndose naturalmente mayor profundidad en la medición completa de los mismos. Los criterios normativos básicos son los siguientes:

1. Funcionalidad (mérito funcional).
2. Presentabilidad (mérito estético).
3. Costeabilidad (mérito económico).

4. Operabilidad (mérito operacional).
5. Conservabilidad natural.
6. Mantenibilidad (facilidad de reparación).
7. Ascabilidad (facilidad de asco).
8. Constructibilidad (mérito constructivo).
9. Seguridad (contra meteoros, robos, etcétera).

Para cada problema particular hay que plantear los criterios evaluativos por utilizar, jerarquizando su importancia relativa en el problema en cuestión. Hay problemas en que la seguridad toma prioridad sobre todos los demás criterios, mientras que en otros el mérito funcional o el estético pasan a primer término.

El problema de la medición del mérito de soluciones competidoras ha sido abordado desde un punto de vista muy especial por la economía de la ingeniería, construyendo escalas monetarias de calificación. Estos mismos procedimientos de calificación pueden realizarse utilizando escalas diferentes a las monetarias para aquellos criterios que no se pueden medir con relaciones de costo/beneficio.

Sin embargo, aspectos tales como la operabilidad, conservabilidad, constructibilidad y aun la seguridad, son todos reducibles a relaciones de costo/beneficio.

También es factible utilizar escalas de mérito basadas en indicadores indirectos que permitan calificar las soluciones con respecto a los criterios. La operabilidad de una solución hospitalaria no sólo puede ser medida directamente en base al monto de los sueldos del personal y los gastos de operación del equipo, sino también a través de indicadores indirectos simples como el número m² de circulación por cama. Estos indicadores indirectos sencillos pueden muchas veces substituir complicados estudios económicos, difíciles de realizar en las etapas tempranas de un proyecto.

Los criterios que han de normar la solución de un problema arquitectónico son el complemento de sus restricciones externas e internas, integrándose así el cuerpo completo de especificaciones generales del problema particular.

SINTESIS

Los métodos tradicionales de la programación arquitectónica son insuficientes para adecuar los proyectos a las necesidades de los usuarios.

La ciencia de sistemas puede hacer una apreciable contribución cambiando el alcance y los métodos de la programación arquitectónica, subsanando esas deficiencias.

Utilizando el punto de vista de sistemas, se puede visualizar todo edificio como un sistema compuesto por otros sistemas y subsistemas, haciendo posible aplicar la metodología de la ciencia de sistemas a estas unidades.

Los sistemas básicos de que consta un edificio desde un punto de vista funcional, son la infraestructura, la estructura, la superestructura y las instalaciones. En cambio desde un punto de vista morfológico el edificio se puede desglosar en sistemas y subsistemas de espacios arquitectónicos (locales, secciones, servicios).

El desglose de todo problema arquitectónico en sus sistemas componentes tiene, ante todo, el mérito de proporcionar un adecuado grado de autonomía a cada sistema, delimitando adecuadamente el campo profesional de los diversos especialistas y proporcionando su colaboración para la optimización del problema total.

La labor de programación ha de consistir entonces en plantear para cada problema el cuerpo completo de sus especificaciones de proyecto, que son básicamente de tres tipos:

1. Especificaciones de funcionamiento (*performance specifications*).
2. Especificaciones materiales (*material specifications*).
3. Especificaciones de producción (*production specifications*).

Estas especificaciones son anteriores al proyecto, y sirven de referencia común a todos los proyectistas que presentan soluciones alternativas del problema, expresando todas las restricciones y requisitos que han de respetar y satisfacer en el proyecto.

La determinación de las especificaciones de proyecto tiene que remontarse al análisis de tres factores objetivos, a los que se denomina factores externos, en los que reside la génesis de las especificaciones de proyecto.

Los análisis de estos factores son tres:

1. Análisis de las actividades de uso del edificio, de los futuros ocupantes.
2. Análisis del sitio o medio del edificio.
3. Análisis de los recursos disponibles.

El análisis de estos tres factores objetivos permite deducir las características que debe reunir el edificio por proyectar, los cuales se expresan en las citadas especificaciones de proyecto.

El desglose del edificio en sistemas tiene un alcance todavía más profundo. Es el enfoque que corresponde a la era industrial de la arquitectura, en que los edificios, más que construirse artesanalmente, ya se empiezan a producir como objetos auténticamente industriales.

La producción industrial es por naturaleza de carácter masivo, estandarizado y repetitivo, realizando partes comunes para diferentes problemas.

Para poder adecuar estos componentes parciales industrializados a los diferentes problemas arquitectónicos, hay necesidad de utilizar el enfoque de sistemas, que permite que el industrial pueda producir los sistemas que se demandan, y que se expresan en las especificaciones de proyecto.

Una arquitectura industrializada sólo puede existir y evolucionar si está relacionada con las demandas a través de especificaciones que le permitan descubrir las demandas comunes de los diferentes problemas arquitectónicos, estandarizando y uniformando su producción en la medida de lo posible, sin restringir innecesariamente las soluciones arquitectónicas.

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INDICE

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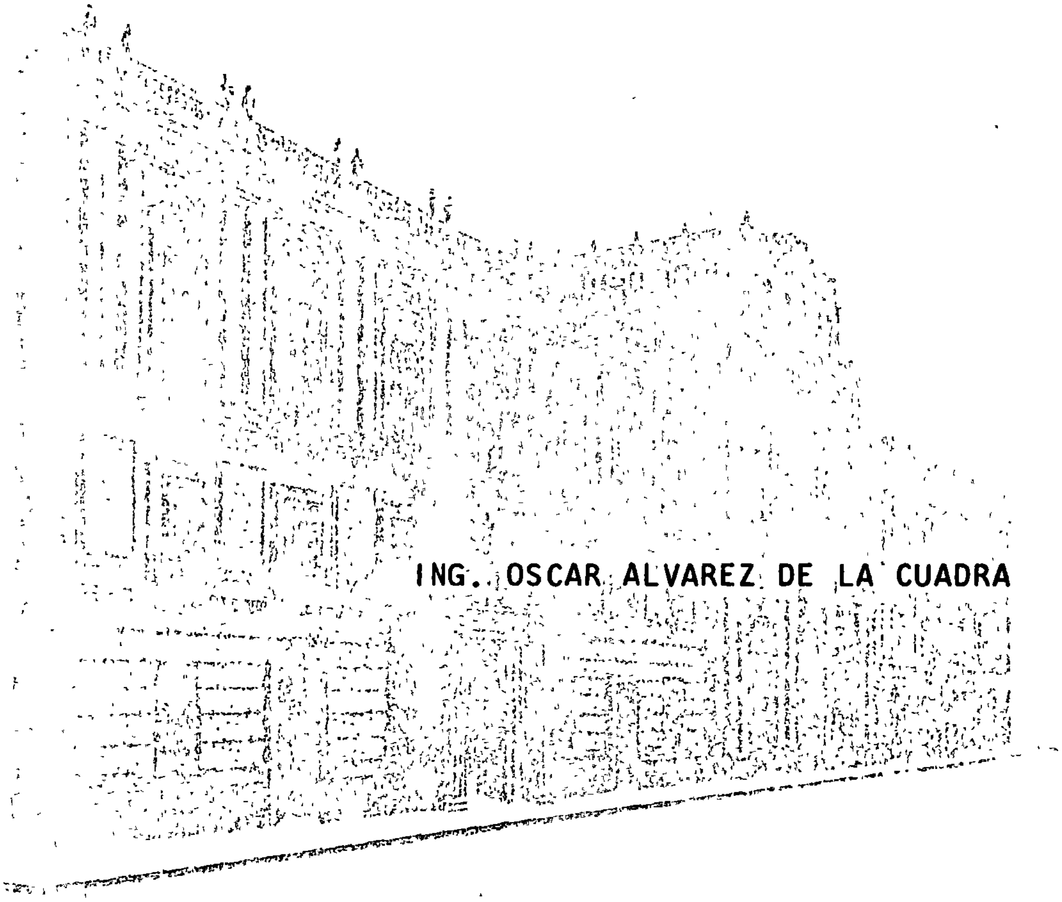
facultad de ingeniería, unam

ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS



ING. OSCAR ALVAREZ DE LA CUADRA

Tacuba 5, primer piso. México 1, D.F.
Teléfonos: 521-30-95 y 513-27-95

GESTIONES Y TRAMITES PARA LA OBTENCION DE LICENCIAS PARA LA CONSTRUCCION.

1.- Solicitud de licencia construcción.

2.- Solicitud de alineamiento y número oficial.

3.- Solicitud de instalación de agua.

4.- Solicitud de conexión al drenaje.

5.- Solicitud para aprobación de la Secretaría de Salubridad.

6.- Solicitud para instalación de gas ante la Dirección General de Gas.

7.- Solicitud antropología e historía.

8.- Manifestación de terminación de obra.

9.- Permiso S.I.C., para instalación de enrgía eléctrica.

'mcpm.

DEPARTAMENTO DEL DISTRITO FEDERAL
DIRECCION GENERAL DE OBRAS PUBLICAS
OFICINA DE LICENCIAS E INSPECCION
DE CONSTRUCCIONES PRIVADAS

(1) FOLIO	
FECHA DE INGRESO	 AÑO MES DIA

SOLICITUD DE LICENCIA PARA ____________________
(OBRA NUEVA, AMPLIACION, MODIFICACION, REPARACION, REGISTRO)

DEL ____ DE ____________ DE ______ AL ____ DE ____________ DE ______ (________ DIAS) (2)
DIA MES AÑO DIA MES AÑO TOTAL DE DIAS

UBICACION			
CALLE		Z. P.	
No. OFICIAL		COLONIA	

ANTECEDENTES	
No. DE LIC. ANTERIOR	
FECHA	

DATOS DEL PERITO O SOLICITANTE			
NOMBRE		R. F. C.	
DOMICILIO		TEL.	
No. DE REG.		No. DE GRUPO	

VALOR DEL TERRENO	$
VALOR DE LA CONSTRUCC.	$
VALOR TOTAL	$

SUPERF. TERRENO	M2
CONSTRUIDA P. BAJA	
CUBIERTA POR AMPL.	
ESTACIONAMIENTO	
NO CONSTRUIDA	

SUPERFICIE POR CONSTRUIR O REGISTRAR	
−3	M2
−2	
−1	
P. B.	
1	
2	
3	
4	
5	
6	
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8	
9	
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11	
12	
13	
14	
TOTAL	

DESCRIPCION DE LA OBRA:

SE ANEXAN LOS DOCUMENTOS SIGUIENTES			
DE TRAMITE		TECNICOS	
COMPROBANTE No. OFICIAL		PLANOS ARQUITECTONICOS	
COMPROBANTE ALINEAMIENTO		PLANOS ESTRUCTURALES	
COMPROBANTE CERT AGUA		MEMORIAS CALCULO	
MANIFESTACION TERMINAC.		CONDOM. SALUBRIDAD	
AUTORIZACION UBICACION		CONDOM. AGUAS	

PROPIETARIO					
NOMBRE				R. F. C.	
DOMICILIO					
COLONIA		Z. P.		TEL.	
OCUPACION		NACIONALIDAD			

PROPIETARIO	PERITO	REVISO	AUTORIZO

1 Y 2 DEBERAN SER LLENADOS POR LA OFICINA

NOTAS: ANTES DE ENTREGARLA FAVOR DE VERIFICAR QUE ESTEN LLENOS TODOS LOS RENGLONES QUE CORRESPONDAN.

1. Esta forma se presentará por duplicado.

2. Para el caso de licencia de obra nueva se anexarán los siguientes documentos:

   a) Certificación de agua en la misma solicitud (por el reverso) o Boleta de Agua.
   b) Núm. oficial y alineamiento (por duplicado).
   c) Memoria de cálculo (por duplicado).
   d) Planos estructurales (por duplicado)
   e) Planos arquitectónicos (mínimo dos juegos).
   f) En el caso de que la construcción sea casa habitación unifamiliar, anexar declaración específica, del director responsable.

3. Para el caso de registros de obra ejecutadas sin licencia, se anexarán los siguientes documentos:

   a) Solicitud por duplicado.
   b) Núm. oficial (por duplicado)
   c) Manifestación de terminación (por duplicado sellada de recibida).
   d) Planos arquitectónicos (dos juegos mínimo)

[illegible]

DEPARTAMENTO DEL DISTRITO FEDERAL
DIRECCION GENERAL DE OBRAS PUBLICAS
OFICINA DE LICENCIAS E INSPECCION
DE CONSTRUCCIONES PRIVADAS

(1) FOLIO			
FECHA DE INGRESO	AÑO	MES	DIA

SOLICITUD DE LICENCIA PARA OBRA NUEVA
(OBRA NUEVA, AMPLIACION, MODIFICACION, REPARACION, REGISTRO)

DEL .... DE .... DE .... AL .... DE .... DE .... (........ DIAS) (2)
DIA MES AÑO DIA MES AÑO TOTAL DE DIAS

U B I C A C I O N

CALLE	[illegible]	Z.P.	21
No. OFICIAL	29	COLONIA	COYOACAN, D. F.

A N T E C E D E N T E S

No. DE LIC. ANTERIOR	
FECHA	

D A T O S D E L P E R I T O O S O L I C I T A N T E

NOMBRE	[illegible]	R.F.C.	[illegible]
DOMICILIO	[illegible]	TEL.	
No. DE REG.	[illegible]	No. DE GRUPO	[illegible]

VALOR DEL TERRENO	$ 100,000.00	SUPERF. TERRENO	100.00 M2.
		CONSTRUIDA P.BAJA	90.00
VALOR DE LA CONSTRUCC.	$ 250,000.00	CUBIERTA POR AMPL.	
VALOR TOTAL	$ [illegible]	ESTACIONAMIENTO	
		NO CONSTRUIDA	10.00

SUPERFICIE POR CONSTRUIR O REGISTRAR	
-3	
-2	
-1	
P.B.	90.00
1	90.00
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
TOTAL	180.00

DESCRIPCION DE LA OBRA
Construcción de casa habitación en 2 niveles
[illegible]

SE ANEXAN LOS DOCUMENTOS SIGUIENTES

DE TRAMITE		TECNICOS	
COMPROBANTE No. OFICIAL	X	PLANOS ARQUITECTONICOS	[illegible]
" ALINEAMIENTO	X	" ESTRUCTURALES	[illegible]
" CERT. AGUA	X	MEMORIAS CALCULO	[illegible]
MANIFESTACION TERMINAC.		CONDOM. SALUBRIDAD	
AUTORIZACION UBICACION		" AGUAS	

P R O P I E T A R I O

NOMBRE	Constructora VDT, S. A.			R.F.C.	CVT-691020
DOMICILIO	Bajío 335-403				
COLONIA	Roma	Z.P.	7	TEL	
OCUPACION	Constructora	NACIONALIDAD	Mexicana		

12 [illegible]

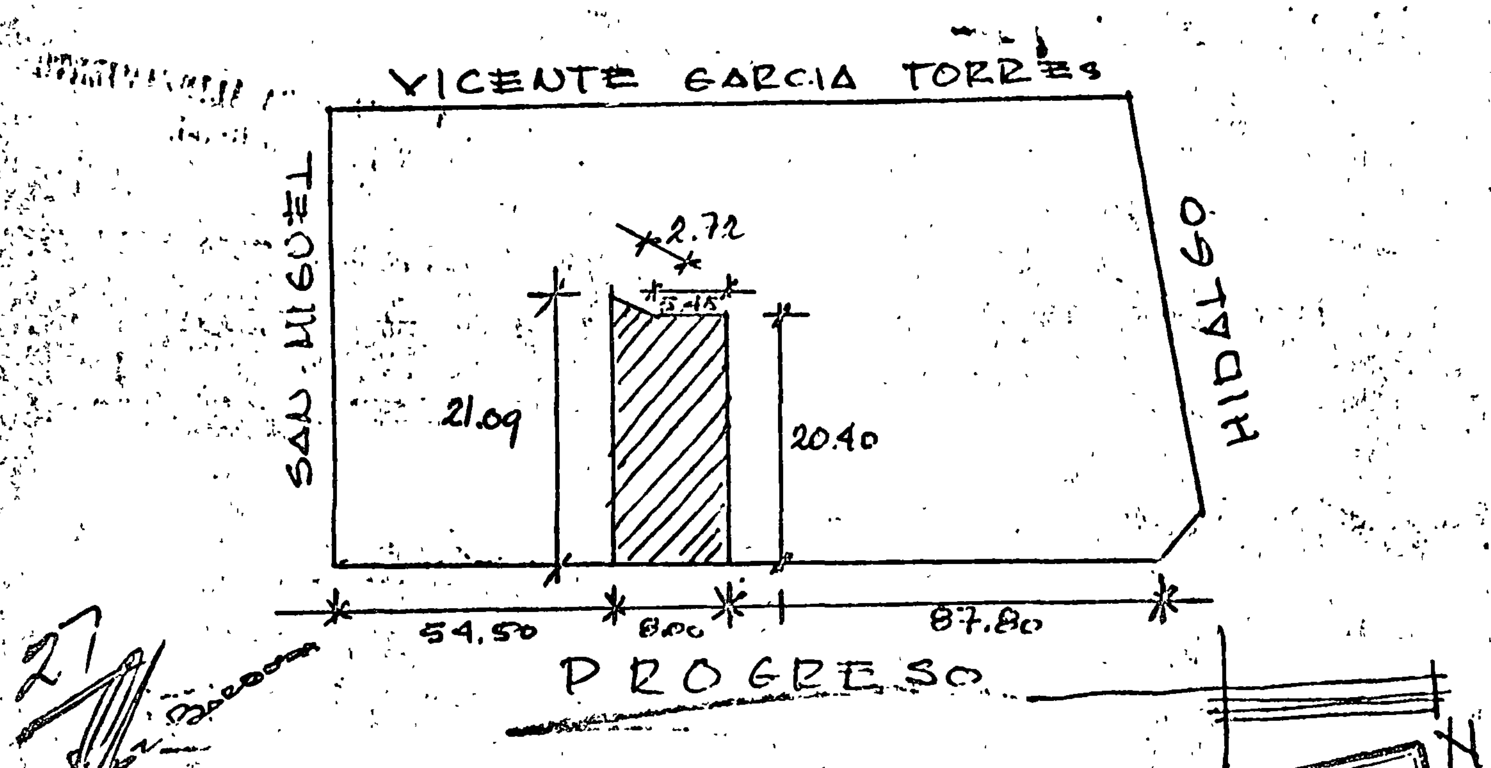
PROPIETARIO	PERITO	REVISO	AUTORIZO

(1) (2) DEBERAN SER LLENADOS POR LA OFICINA

De venta en Pap. Navarro, S. A. Uruguay 80 y Liverpool 75-A

Forma No. 102

LUGAR PARA EL CROQUIS QUE SE DEBE HACER CON TINTA



DATOS DEL TOPOGRAFO

Estado del Predio .... Colinda el predio ....
(Baldío, fincado, en construcción) (Avenida en proyecto, escuela, parque, glorieta, etc.)

Clase de Construcción .... Zona ....
(Habitación, barda bodega, fábrica, taller) (Residencial, Industrial, Comercial, Arqueológica, etc.)

SIRVASE PROCEDER A COLOCAR EL NUMERO DESIGNADO

DEPARTAMENTO DEL DISTRITO FEDERAL
DIRECCION GENERAL DE OBRAS PUBLICAS
JUN. 5 1970
PLANIFICACION
SECCION DE ALINEAMIENTOS Y NUMEROS OFICIALES

DEPARTAMENTO DEL DISTRITO FEDERAL

DIRECCION GENERAL DE OBRAS PUBLICAS Y OFICINAS DE PLANIFICACION

Mesa de Números Oficiales Comprobante Número 4-2348

Esta Oficina ha señalado el Número Oficial 27 para la entrada del predio

ubicado en la CALLE PROGRESO.

COYOACAN, D.F.

México, D. F., a 5 de JUNIO de 1970

El Jefe de la Sección de Alineamientos
y Números Oficiales

ING. SERGIO NEGRETE MORA.

Nota:—Este comprobante debe conservarlo en su poder el interesado o el propietario y mandar colocar inmediatamente el número señalado, de lo contrario se levantará la infracción correspondiente. Indíquese a quien instale la toma de agua que ponga en el zaguán precisamente donde se coloque el Número Oficial.

"EL RUBI"
Seminario 16
22-83-05
Claudio Bernard 150
Tel. 10-14-21
México, D. F.
No. 7

~~FORMA 7~~

ANEXO 1''

AUD 220-VIII-71

RPsrcr-21

DEPARTAMENTO DEL DISTRITO FEDERAL

OFNA. DE LICENCIAS DE CONSTRUCCION
(DEPENDENCIA ORDENADORA)

I 137787 MAY-12-72

LUGAR PARA LA MARCA DE LA MAQUINA REGISTRADORA

589458 • • 87 261C0B — 105.00

C. CAJERO NUM. 261.

ESTE DOCUMENTO SOLO TIENE VALOR COMO RECIBO SI LLEVA IMPRESA LA MARCA DE LA MAQUINA REGISTRADORA DE LA TESORERIA DEL DISTRITO FEDERAL.

TESORERIA DEL DISTRITO FEDERAL

SIRVASE USTED RECIBIR DE: EL C. PROPIETARIO CONSTRUCTORA VET S.A.

CON DOMICILIO EN: PROGRESO No. 29 COL. COYOACAN

NUMERO DE CUENTA:

LA CANTIDAD DE: (CIENTO CINCO PESOS 00/100)
EL TOTAL CON LETRA

POR CONCEPTO DE: PAGO INICIAL DE OBRA NUEVA

CUOTA	$ 105	00
MULTA		
ADIC. 15 %		
RECARGOS		
COBRANZA		
EMBARGO		
TOTAL	$ 105	00

NOMBRE, FIRMA Y SELLO DEL JEFE DE LA DEPENDENCIA ORDENADORA

NUMERO Y FIRMA DEL CAJERO RECAUDADOR

ABONESE A:

MEXICO, D. F., A 11 de mayo DE 19 72

ORIGINAL - INTERESADO

ROYAL MERES NUM. 6436

FORMA 8

ANEXO 1'''

DEPARTAMENTO DEL DISTRITO FEDERAL

DIRECCION GENERAL DE OBRAS PUBLICAS

OFICINA DE LICENCIAS E INSPECCION DE CONSTRUCCIONES PRIVADAS

Nº 22191

Lic. 1/2302/72/04 obra NUEVA

Fecha de expedición 2 DE JUNIO DE 1972

UBICACION

Calle: PROGRESO.

Núm. oficial: 29

Colonia: COYOACAN D.F.

DIRECTOR RESPONSABLE DE OBRA

Nombre: ING. ARMANDO RODRIGUEZ SANCHEZ.

Núm. registro: 2270

Grupo: PRIMERO.

PROPIETARIO

CONSTRUCTORA VET. S.A.

Estacionamiento: proporciona 30.00 m² en PLANTA BAJA.

con DOS vehículos

Alineamiento Núm. 8114/72

Valor terreno $ 100,000.00

Valor construcción $ 150,000.00

Fecha: 24 de abril de 1972.

Notas: ANTICIPO: 137787-$105.00
PARA CONSTRUIR CASA HABITACION UNIFAMILIAR EN DOS NIVELES, EN DOS NIVELES, CON UNA SUPERFICIE DE 280.00 M2, sin volado que invada la vía publica. Esta licencia y los planos aprobados, deberán permanecer en la obra para ser mostrados al inspector. La superficie de estacionamiento no podrá destinarse a otro uso.
118/72: (FUERON PRESENTADOS A ESTE DEPARTAMENTO, SOLICITUD Y PLANOS PARA EJECUTAR OBRA NUEVA, EN LA DIRECCION ARRIBA INDICADA: La H. Comisión de Monumentos Coloniales, en su dictamen del día 27 de abril del presente año, autorizó dicha obra, la que deberá realizarse de acuerdo con los planos sellados y aprobados, por este Departamento debiendo continuar su trámite ante el Departamento del Distrito - -
SALDO DEL: ANTICIPO No. 137787 $ 105.00 - - - - (VUELTA

Importe de derechos $ 190.00 (CIENTO NOVENTA PESOS 00/100) Revisó

12 meses a partir de la fecha.

ARQ. JORGE AGUILAR. mc/

(a) Federal. Notifíquese la fecha en que se concluya la obra mencionada. México D.F., a 9 de mayo de 1972.- El Jefe del Departamento. Rubrica Arq. Ignacio Angulo Villaseñor.- Al margen un sello que dice Sria. de Educación Publica.- Inst. Nacional de Antropologia e Historia Depto. de registro licencias e inspección.-

MGP/mos.

PUEDE AUTORIZARSE AL ING. ARMANDO RODRIGUEZ SANCHEZ, PARA OBRA NUEVA EN LA CASA No. 29 DE LA CALLE DE PROGRESO, COYOACAN D.F., SUJETANDOSE AL SIGUINTE DICTAMEN.- -

ANEXO 2

SOLICITUD DE ALINEAMIENTO Y NUMERO OFICIAL

C. DIRECTOR DE PLANIFICACION DEL DDF.
OFICINA DE LICENCIAS DE CONSTRUCCION.

El suscrito solicita le sea dado **Alineamiento** ☐

Número Oficial ☐

que corresponderá al predio que actualmente tiene el número ______________________ de la calle ____ según los datos que se consignan en el croquis al reverso, en la inteligencia de que la entrada que se proyecta está situada como se indica en el croquis.

Boleta de Contribuciones Núm. ____________________ **Manzana** ____________ **Lote** ____________

Calle ____ **Colonia** ____________________

Obra que se va a ejecutar ____

México, D. F., a ______ **de** ______________________ **de 19** ______

Nombre completo del Solicitante.

____

____
FIRMA

Nombre completo del propietario ____

Dirección del propietario ____

____

El propietario del predio se hace responsable de los datos y croquis que se presentan.

Restricciones:

________________________________ ________________________________
FIRMA DEL PROPIETARIO AUTORIZO

PAPELERIAS GRAFOS, S. A.
PORTAL DE STO. DOMINGO LOCALES E Y F TEL. 521-12-88
DR LAVISTA 143 (FRENTE A LA TESORERIA)
MEXICO 7, D. F. TELS. 588-16-57 588-02-92

LUGAR PARA EL CROQUIS

IMPORTANTE: TODOS LOS CROQUIS DEBERAN SER A TINTA. ESTE DOCUMENTO NO DEBERA PRESENTAR TACHADURAS NI ENMENDADURAS.

DATOS QUE DEBE CONTENER EL CROQUIS DE LA MANZANA Y EL PREDIO:

NOMBRE DE LAS CALLES QUE LIMITAN LA MANZANA, DISTANCIA DE LAS DOS ESQUINAS A LOS LINDEROS DEL PREDIO, DISTANCIA DE UNA DE LAS ESQUINAS A LA MITAD DE LA ENTRADA DEL PREDIO, MEDIDA DEL FRENTE O FRENTES, FONDO DEL PREDIO Y ORIENTACION.

DEPARTAMENTO DEL DISTRITO FEDERAL

DIRECCION GENERAL DE PLANIFICACION
OFICINA DE LICENCIAS DE CONSTRUCCION

Sección de Alineamientos y Números Oficiales, Comprobante Núm. ____________________

Esta Oficina asignó el Número Oficial ____________ **Al predio ubicado en** ____________

____

Colonia ____

México, D. F., a ____ **de** ____________ **de 19** ____

EL JEFE DE LA SECCION DE
ALINEAMIENTOS Y NUMEROS OFICIALES

ANEXO 3

REGISTRO ____________ EXPEDIENTE. ____________

DEPARTAMENTO DEL DISTRITO FEDERAL.
Dirección Gral. de Aguas y Saneamiento.
Oficina de Conexiones y Medidores.
Presente.

SOLICITUD para ____ de
(Instalación, Ampliación o cambio de lugar)

una toma de agua para ______________________________ de ____________ mm.
Predio, Industria, Comercio

de diámetro ______________ materiales, de acuerdo con las siguientes
(Con o sin)

ESPECIFICACIONES

UBICACION: Núm. ____________ Calle ______________________________

Colonia ______________________________ Delegación ____________________

Destino del predio ______________________________ Bta. Predial ____________________

Nombre del Propietario ____

Dom. Particular Núm. ____________ Calle ____________________ Col. ____________

OBSERVACIONES: ____

____

____

NOTA:- Estoy conforme con la cuota que se aplique a esta Toma, de acuerdo con el diámetro y uso de la misma y sin derecho a posterior reclamación.

México, D. F. a ______ de ____________________ de 19 ___

____
Firma

CERTIFICADO DE LA OFICINA DE NUMEROS OFICIALES.

El Núm. ____________ es oficial.

____
Firma

Sello

INSTRUCCIONES:

1.- Las solicitudes se formularán por TRIPLICADO.

2.- En el predio deberá fijarse el número oficial y señalarse el lugar para la toma.

3.- Las tomas se instalarán en la entrada principal del predio y sólo en casos especiales se concederán en locales pertenecientes al mismo y siempre que tengan acceso directo de la Vía Pública al interior.

4.- Los presupuestos y órdenes de pago serán recogidos por los interesados en la ventanilla de "Presupuestos de Tomas"

5.- Queda a la elección del solicitante el proporcionar o pagar los materiales necesarios para las instalaciones de 12mm. (½"), siempre que no sea dentro del primer cuadro, en donde invariablemente los interesados lo proporcionarán, así como para ampliaciones, cambios de lugar y reducciones, en cualquier parte que se solicite.

6.- Se dibujará un croquis de la manzana en que se encuentre el predio, con los nombres de las calles que la limiten, señalando la distancia de la esquina más cercana al lugar donde se deba de instalar la toma.

LUGAR PARA EL CROQUIS:

ANEXO 5

SOLICITUD DE APROBACION
RECIBASE CON ________
AUTORIZADO POR ________

Sup. Total de Terreno
________ M2.

Sup. construida en los distintos niveles.

Sótano ________ M2.
P. B. ________ M2.
Mezzanine ________ M2.
1o.- ________ M2.
2o.- ________ M2.
3o.- ________ M2.
4o.- ________ M2.
5o.- ________ M2.
6o.- ________ M2.
7o.- ________ M2.
8o.- ________ M2.
9o.- ________ M2.
10o.- ________ M2.
11o.- ________ M2.
12o.- ________ M2.
13o.- ________ M2.
14o.- ________ M2.
15o.- ________ M2.

SUMA TOTAL ________ M2.

Sup. Cubierta por la Ampliación ________ M2.

Sup. no construida
________ M2.

DERECHOS: $________

____
____
____
____
____
____
____
____
____

PAPELERIAS "GRAFOS, S.A."
PORT.STO.DOMINGO LOC. E-F.
DR. LAVISTA No. 143.
TELS. 521-12-88 y 588-16-57

SECRETARIA DE SALUBRIDAD Y ASISTENCIA.
DIRECCION GRAL. DE SALUBRIDAD EN EL D. F.
DIRECCION DE INSPECCION SANITARIA.
INGENIERIA SANITARIA.

Presente.

El que suscribe ________
Responsable o propietario.

Con Céd. de la Direc. de Profs. No. ________

y con domicilio Prof. ________
____

Solicita la autorización, de acuerdo con el Reglamento de Ing. Sanitaria, de los planos que se anexan con los siguientes datos:

OBRA POR EJECUTAR ________
Const. Nueva, Reconstruc., Ampl.,
____
Modificación, Regularización.

AVANCE DE OBRA ________

DESTINO DE LA OBRA ________
Casa Hab.,Deptos., Cond., etc.

UBICACION DEL PREDIO: Calle ________
No.________ Col.________ Z.P.____

NOMBRE DEL PROPIETARIO ________

DOMICILIO DEL PROPIETARIO: Calle ________
No.________ Col.________ Z.P.____

México, D.F., a ____ de ________ de 197____

FIRMA DEL PROPIETARIO FIRMA DEL RESPONSABLE.

________ ________

Constancias de que existen los servicios frente al predio.

No. Of.________ Agua________ Albañal________

Esta solicitud deberá presentarse llena a máquina por cuadruplicado si es REGULARIZACION o quintuplicado si se trata de OBRA NUEVA, dibujando en el reverso de una COPIA el croquis de localización del predio debidamente acotado. Se debe anexar a esta solicitud, INICIALMENTE UN JUEGO DE PLANOS QUE INCLUYAN: PLANTAS CORTES, FACHADAS Y CROQUIS DE LOCALIZACION, INSTALACIONES SANITARIAS, HIDRAULICAS E INST. ESPECIALES, y demás ordenamientos que marca el REGLAMENTO DE ING. SANITARIA RELATIVO A EDIFICIOS, EN VIGOR.
El responsable, deberá estar debidamente registrado en esta Dependencia. Todos los planos deberán estar numerados y firmados por el propietario y el responsable. Los datos consignados en esta solicitud quedan bajo la responsabilidad de los solicitantes.
sirvase pasar a la ofna. de ing. sanitaria 10 días DESPUES DE ENTREGADA SU DOCUMENTACION EN LA OFICIALIA DE PARTES. Si en 30 días no se recaba información sobre esta solicitud, será CANCELADA.

REG. NUM. ______

PTO. NUM ______ ORDEN DE TRABAJO ______

México, D. F. a ______

C. DIRECTOR GRAL. DE AGUAS Y SANEAMIENTO.
OFICINA DEL SERVICIO DE SANEAMIENTO.
PRESENTE.

______ Propietario de la casa Núm ______
de la calle ______ Colonia ______
______ con domicilio particular en la casa Núm. ______
de la calle ______ Colonia ______
Solicita para la primera la ______ manifestando
que la banqueta es de ______ y el pavimento ______

______
FIRMA DEL INTERESADO

MANO DE OBRA

______ Mts. Tierra ______ a $ ______ Ml ______
______ „ Empedrado ______ a $ ______ „ ______
______ „ Tepetate ______ a $ ______ „ ______
______ „ Emparrillado ______ a $ ______ „ POR DIA
______ „ Pavimentos ______ a $ ______ „ ______
100% sobre $ ______ por trabajo urgente ______
50% sobre $ ______ por trabajo de noche ______
Por ______ inspección(es) ______ $ ______

REPARACION DE PAVIMENTOS

______ Mts. Empedrado ______ a $ ______ Ml ______
______ „ Cemento (banqueta) a $ ______ „ ______
______ „ Macadam ______ a $ ______ „ ______
______ „ Asfalto ______ a $ ______ „ ______ $ ______

IMPORTE TOTAL $ ______

Fecha del Presupuesto: México, D. F., a ______
BOLETA DE PAGO POR MANO DE OBRA NUM ______
BOLETA DE PAGO POR REPARACION DE PAVIMENTO NUM ______
Fecha de la orden de trabajo: México, D. F., a ______
Presupuesto ______ P. O. EL JEFE DEL SERVICIO
DE SANEAMIENTO

EL INSPECTOR

DATOS DEL PRESUPUESTO AL SERVICIO ______

______

CONFORMIDAD DEL PROPIETARIO

______
FIRMA

INSTRUCCIONES
A LA VUELTA

MESA DE
CONEXIONES

MESA DE
NUMEROS OFICIALES

SELLO

EL ______ ES NUMERO
OFICIAL

______
AUTORIZACION
PAVIMENTOS

SELLO

PAVIMENTO ______

______

REEXPEDIDA CON FECHA:

SELLO DE REG. BOL.

NOTA:- Las conexiones en emparrillado y concreto deberán cobrarse según el costo al concluir la obra.

INSTRUCCIONES DE CONEXIONES DE ALBAÑAL

Requisitos que deberá llenar el interesado.

I.-La solicitud se formulará por triplicado, conteniendo el croquis correspondiente en el lugar que abajo se indica.

II.-Se recabará el sello del Número Oficial en la oficina correspondiente.

III.-Se presentará la solicitud en la Ventanilla de conexiones de albañal del Servicio de saneamiento (Cuarto Piso) del ex-Palacio Municipal.

IV.-Las boletas que por concepto de Mano de Obra y reparación de Pavimento se le extiende al interesado las deberá cubrir en la caja Núm. 19 del propio Departamento.

V.-Deberán presentarse dichas boletas en la Ventanilla de conexiones para su registro, cuando el material de la lista que se proporcione al interesado se encuentre en el lugar preciso de la obra y a disposicion del Servicio.

VI.-Si al hacer la revisión no se encuentran los materiales en la obra, incurrirán en un recargo de mano de obra que deberá cubrirse para poder hacerse la conexión.

VII.-Todo material no reglamentario será rechazado.

LIMPIAS Y RECONSTRUCCIONES DEL ALBAÑAL

I—El interesado localizará la salida del albañal y habrá siempre persona que informe a los operarios, aún cuando el trabajo deba verificarse de noche y proporcionar el cemento necesario para los taladros.

II.-Si al practicarse la limpia se encuentra que es necesario reconstruir el albañal, se dejará una nota.

III.-El interesado está obligado a proporcionar los materiales de acuerdo con la lista que se le entregue en la Oficina.

NOTA GENERAL:-Los trabajadores no están autorizados para exigir gratificación ni salario extra por las obras que ejecuten, por consiguiente la Dirección no se hace responsable de otros pagos hechos fuera de la Caja Oficial.

PARA SER LLENADO EXCLUSIVAMENTE POR EL SERVICIO

Ejecutada el ____________________

Ejecutada por ____________________

____

____

Obra pendiente ____________________

____

Falta de material ____________________

____

Material incompleto ____________________

____

Material no Regl ____________________

Por no haber quien Inf ____________________

Inserción por atarjea ____________________

Hay preparación ____________________

No hay preparación ____________________ y falta por

____

conectar ____________________

____

OBSERVACIONES ____________________

____

____

____

Devuelta a la oficina el ____________________

Revisó el material ____________________

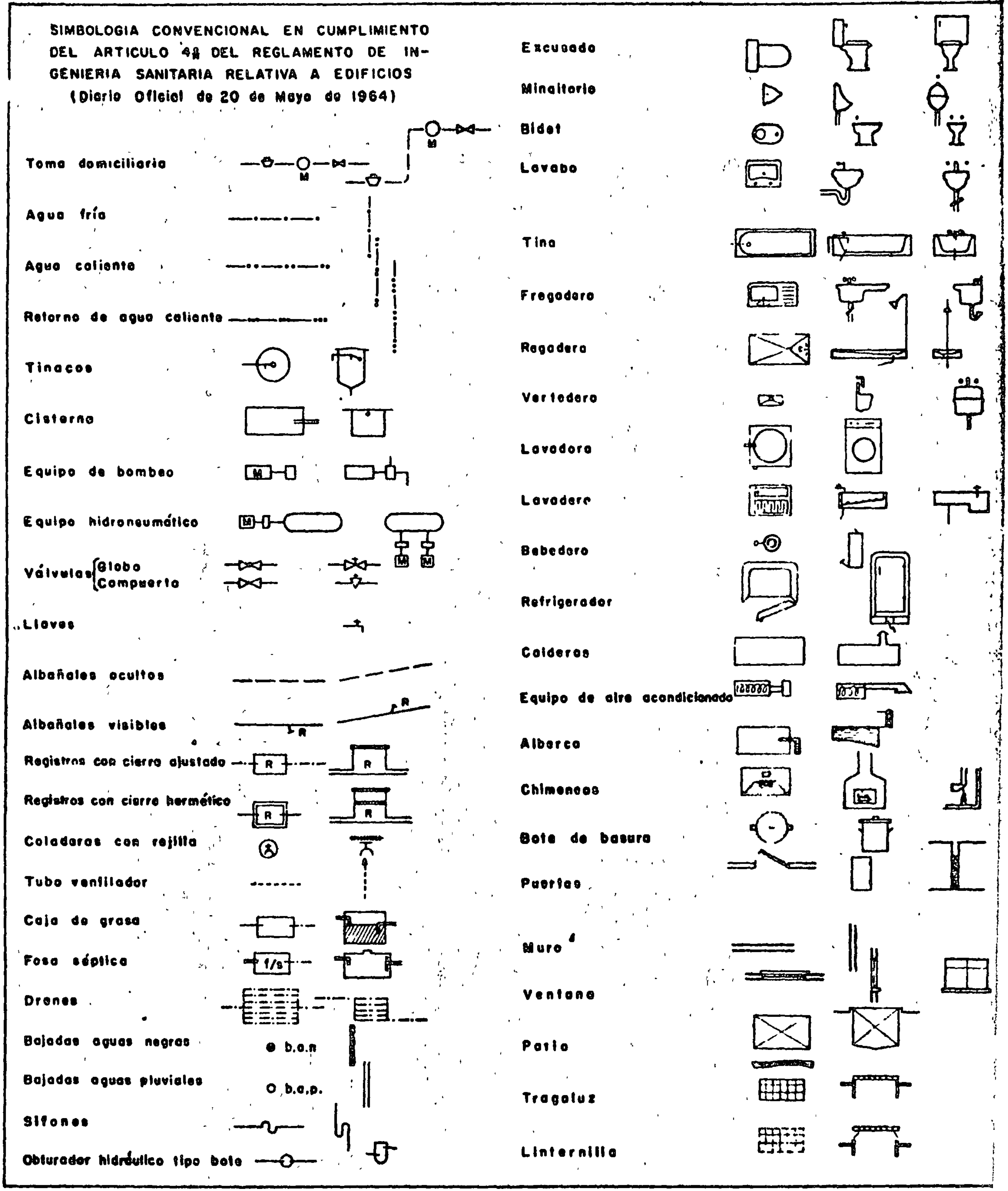
Sobrestante

____

LUGAR PARA EL CROQUIS

Se dibujará el croquis de la Manzana con los nombres de las calles que la limitan; localizando el predio e indicando el lugar de la conexión, así como la distancia entre el eje de ésta a la esquina más próxima. En el predio deberá fijarse el No. Oficial y mediante una señal visible indicar el lugar exacto donde deberá quedar la conexión.

SIMBOLOGIA CONVENCIONAL EN CUMPLIMIENTO DEL ARTICULO 4º DEL REGLAMENTO DE INGENIERIA SANITARIA RELATIVA A EDIFICIOS (Diario Oficial de 20 de Mayo de 1964)



FORMA 9

ANEXO 5"

DIRECCION GENERAL DE SALUBRIDAD EN EL D. F.

DELEGACION ADMINISTRATIVA **OFICINA DE CONTABILIDAD GENERAL**

CAJA GENERAL

RECIBO Nº 45035

CONSTRUCTORA VET, S.A. *Entregó la suma*

de $ 180.00 (CIENTO OCHENTA PESOS 00/100 M.N.)

POR EL SIGUIENTE CONCEPTO: REVISIÓN DE PLANOS PARA CONSTRUCCIÓN EN LA CALLE PROGRESO NO. 29 COLONIA COYOACÁN C.P. 21.

IMPRESO EN SECCION D.G.S.D.F.

México, D. F., 11 *de* MAYO *de* 1972

RECIBI

EL CAJERO

Vo. Bo.

EL JEFE DE LA OFICINA

AUTORIZADO

MAYO 11. 1972

EL DELEGADO ADMINISTRATIVO

SECRETARIA
DE
SALUBRIDAD Y ASISTENCIA

C.G.-2

DIRECCION GENERAL DE
DEPENDENCIA [illegible] D. F.
[illegible] SANITARIA.
[illegible] SANITARIA
SECCION [illegible]
MESA
NUMERO DEL OFICIO 2[illegible]7
EXPEDIENTE 125-VI-512(16)/1031

ASUNTO: SE APRUEBAN PLANOS.

DIRECTO

México, D. F., a 30 JUN. 1972

C. CONSTRUCTORA VET, S. A.
CALLE BAJIO
NUMERO 335-403
COLONIA ROMA
Z. P. 7

En respuesta a su solicitud, registro de entrada No. 42186 de 11 de Mayo/72 manifestamos a usted que se aprueban los planos bajo la exclusiva responsabilidad del C. Ing. Julio Colon Viciana, Céd. Prof. No. 101657, planos que presentó y según los cuales construirá una casa Habitación en el No. 29 de la calle Progreso en la Col. Coyoacán de esta ciudad, propiedad de Constructora Vet, S. A.

Antes de cubrir las instalaciones que van a quedar ocultas, deberá dar aviso oportuno para su inspección.

De no cumplirse con las disposiciones del Código Sanitario y del Reglamento de Ingeniería Sanitaria en vigor, quedará sin efecto esta aprobación y se procederá como corresponda sin perjuicio de que se le apliquen las sanciones respectivas por haber efectuado obras sin llenar los requisitos del caso.

No deberá ser habitado el inmueble de referencia sin que se obtenga el permiso de ocupación de esta Secretaría.

Atentamente.
SUFRAGIO EFECTIVO. NO REELECCION.

EL JEFE OFNA. ING. SANITARIA.	**EL DIRECTOR DE INSPECCION SANITARIA.**
	Calderon
ING. ENRIQUE GUADARRAMA REYES.	**ORLANDO CALDERON GUERRERO.**

CONTESTAR ESTE OFICIO, CITENSE LOS DATOS CONTENIDOS EN EL CUADRO DEL ANGULO SUPERIOR DERECHO

c.c.p. C. Director Gral. de Obras Públicas del Depto. del D.F.,
Plaza de la Constitución.- Ciudad.
c.c.p. Oficina de Ingeniería Sanitaria, Mesa de Inspección de Edificios.- Oaxaca No. [illegible]- 2do. Piso.

DIRECTO

EGR'CSG'cm.

EGR/MAR/grc.
42186/72
12/VI/72

FORMA 5

ANEXO 6 DGG-RP

FOLIO No. 556

SOLICITUD DE AUTORIZACION DEL PROYECTO DE LA INSTALACION DE GAS

En cumplimiento a lo dispuesto por los Artículos 27, 36 y demás relativos del Reglamento de la Distribución de Gas, nos permitimos solicitar a esa Secretaría de Industria y Comercio, la aprobación del proyecto de la instalación de gas L.P. ☒ gas natural ☐ , para lo cual proporcionamos los siguientes datos:

Nombre del Propietario: CONSTRUCTORA VET. S. A.

Domicilio del Propietario: BAJIO No. 335-403, COL. ROMA

Ubicación de la Obra: Calle y No. PROGRESO No. 29

Entre las Calles de: AVENIDA HIDALGO Y SAN MIGUEL

Población: COYOACAN Entidad Federativa: MEXICO 20, D. F.

CLASE: [✓ A] B C D

I.- RECIPIENTES.

Portátiles ☐ Fijo ☐
2 tanques de 72 lts. c/u

II.- REGULADOR DE PRESION.

Cantidad:	Capacidad:		Presión de salida:	
1	0.98	M^3/H.	27.94	g/cm^2
		M^3/H.		g/cm^2
		M^3/H.		g/cm^2

III.- TUBERIAS.

a).- De Llenado.

Líquido:	Material:	Tipo:	Diámetros:	Desfogue
				SI
				NO

Vapor:	Material:	Tipo:	Diámetros:

NOTA: Esta solicitud deberá ser llenada a máquina.

b).- De Servicio.

Material:	Tipo:	Diámetros:
Cu. Rígs.	L	12.7mm
Cu. Flex.		9.5mm

IV.- MEDIDORES.

Cantidad:		Capacidad de c/u:	M³/H
			M³/H

V.- APARATOS DE CONSUMO.

Cantidad:	Tipo:	Capacidad:	
1	Estufa 4QH	0.418	M³/H
1	Cal. Alm.	0.259	M³/H
			M³/H

Con los datos asentados en esta solicitud se realizará la instalación, observando además las Disposiciones contenidas en el Reglamento de la Distribución de Gas, en el Instructivo correspondiente y aquellas otras que al respecto dicte la Secretaría de Industria y Comercio.

Se acompaña a la presente los planos por triplicado, de la misma, formulados por el C. Fernando F. Blumenkron G., Técnico Responsable autorizado por esa Secretaría y registrado con el No. B-19

Lugar y Fecha México, D. F., 25 de Abril de 1972.

Firma Técnico Responsable.

Firma del Propietario.

- -

Para ser llenado por la D.G.G.

Recibió ____________________

Derechos ____________________

FORMA 10

ANEXO 7

INSTITUTO NACIONAL DE ANTROPOLOGIA E HISTORIA

DEPARTAMENTO DE REGISTRO, LICENCIAS E INSPECCION

ORDEN DE COBRO Nº Nº 461

CERTIFICACION DE COBRO DE LA TESORERIA

I.N.A.H. S.E.P. DEPARTAMENTOS TES Y ADMON. PAGADO CUOTA ASIGNADA

FIRMA

IMPORTE 280.00

C. JEFE DEL DEPARTAMENTO DE TESORERIA Y ADMINISTRACION

SIRVASE RECIBIR DE CONSTRUCTORA VET, S.A.

CON DOMICILIO EN PROGRESO No. 29 (CALLE) COYOACAN, D.F. (ZONA MONUMENTAL)

LA CANTIDAD DE $ 280.00 (NUMERO) (DOSCIENTOS OCHENTA PESOS 00/100 M.N.) (LETRA)

POR CONCEPTO DE DERECHOS POR

☒ LICENCIA DE OBRA ☐ LICENCIA DE ANUNCIO ☐ REGISTRO ☐ PERMISO

No. 188/72

Para Solicitante

CODIFICACION				LIQUIDACION		
I	II	III	IV	CUOTA FIJA		100.00
A-1				IMPORTE POR M ^{2}	1.00	180.00
				IMPORTE POR PIEZA		
				TOTAL		280.00

Hecho por: SPN

Revisó: MGP

México D F. a 9 de mayo de 1972

RLI-3

Distrito Federal

118/72

SECRETARIA DE EDUCACION PUBLICA
INSTITUTO NACIONAL DE ANTROPOLOGIA E HISTORIA
DEPARTAMENTO DE MONUMENTOS COLONIALES

MESA DE LICENCIAS **LICENCIA PARA OBRA EXTERIOR**

Puede autorizarse al ING. ARMANDO RODRIGUEZ SANCHEZ.

para OBRA NUEVA.

en la casa Núm. 29. la de calle de PROGRESO.

COYOACAN, D. F.

sujetándose al siguiente dictamen:

Fueron presentados a este Departamento, solicitud y planos para ejecutar obra nueva, en la dirección arriba indicada.

La H. Comisión de Monumentos, en su dictamen del día 27 de abril del presente año, autorizó dicha obra, la que deberá realizarse de acuerdo con los planos sellados u aprobados por este Departamento, debiendo continuar su trámite ante el Departamento del Distrito Federal.

Notifíquese la fecha en que se concluya la obra mencionada.

ESTADOS UNIDOS MEXICANOS

SECRETARIA DE EDUCACION PUBLICA
INSTITUTO NACIONAL DE ANTROPOLOGIA E HISTORIA
DEPARTAMENTO DE REGISTRO LICENCIAS E INSPECCION

EL JEFE DE LA SECCION DE LICENCIAS

México, D. F. a 9 de mayo de 1972.

EL JEFE DEL DEPARTAMENTO

ARQ. IGNACIO ANGULO VILLASEÑOR.

MGP'mes

ESTA LICENCIA CADUCA AL AÑO DE SU EXPEDICION

ANEXO 8

AUD. 9/68.

NUMERO DE CUENTA DEL IMPUESTO PREDIAL....................

NUM. DE CTA. DE DERECHOS POR SERV. DE AGUAS....................

MANIFESTACION DE....................

(Construcción, ampliación o reconstrucción)

C. DIRECTOR GENERAL DE OBRAS PUBLICAS
Presente.

....................de profesión u ocupación....................
....................originario de....................de nacionalidad....................
con domicilio en....................
(Zona postal)
Manifiesta a usted: que con fecha....................
....
(Se terminó - Pasó a ocupar sin terminar - La casa, pieza, etc.)
Ubicación del predio: Lote....................Manzana....................Calle....................
Número....................Colonia....................Zona postal....................
Destino del predio:....................
(Rentado u ocupado por su propietario) (Viviendas, Locales, Apartamientos para rentar. Dígase el Núm. de éstos)
Descripción de las piezas o locales:....................
(Descríbase con precisión número y clase)
....
Servicios urbanos con que cuenta la calle:....................
(Agua - Atarjeas - Banquetas - Pavimento - Alumbrado)

DESCRIPCION DE LAS CONSTRUCCIONES DEL INMUEBLE

Cimentación:....................
(Mampostería de piedra) (Concreto reforzado)
Muros:....................
(Adobe - Tepetate - Tabique sin refuerzos - Tabique con refuerzos de concreto) (Estructura de concreto con muros de relleno)
Techos:....................Pisos:....................Motivos decorativos:....................
....................Instalación eléctrica....................Combustible....................
(Visible - Oculta - etc.) (Gas - Petróleo - Leña)
Instalaciones especiales:....................
(Elevadores Calefacción central - Aire acondicionado - etc.)
Amparado con Licencia de Construcción número:....................

SUPERFICIES DEL INMUEBLE:

Lo que comunico a esa Dirección, para los fines consiguientes. Declaro que los datos consignados en la presente son verídicos y me hago responsable de las violaciones que pudieran haberse cometido, conforme al Reglamento de las Construcciones, con motivo de esta obra.

México, D. F., a

....
(FIRMA DEL PROPIETARIO O POSEEDOR)

CROQUIS DE LOCALIZACION

Certificación de la Oficina de Números Oficiales:

DATOS QUE DEBE CONTENER EL CROQUIS

a).—Distancia de las dos esquinas a los linderos del predio.

b).—Medida del frente o frentes y fondo del predio.

c).—Nombre de las calles que circundan la manzana en que se encuentra ubicado el predio.

NOTA: Los datos anteriores deben corresponder a los del número oficial.

—PRESENTARSE POR OCTUPLICADO—

TRAMITES ANTE LA
SECRETARIA DE INDUSTRIA Y COMERCIO.

Aprobación del Departamento de Inspección e Instalaciones Eléctricas del Proyecto.

Requisitos:

1.- Solicitud efectuada por Ingeniero registrado en S.I.C. conteniendo:

   1.1 Nombre del Propietario.
   1.2 Ubicación de la Obra.
   1.3 Número de Lámparas.
   1.4 Número de Contactos.
   1.5 Número de Motores y sus especificaciones.

2.0 Plano de la Construcción en donde se indique el lugar donde estarán colocadas todas las instalaciones.

3.0 Demanda de Energía.

4.0 Inspección para Verificación.

'mcpm.

OBRAS E INSTALACIONES.-

Las obras e instalaciones eléctricas deberán llenar los requisitos que les sean aplicables del presente reglamento "Reglamento de obras e instalaciones eléctricas",salvo que en algún caso la Secretaría de Economía las exima de alguno de dichos requisitos,de acuerdo con los artículos 33 y 24 de la Ley de la Industria Eléctrica y demás disposiciones correlativas.

Al solicitar la autorización a que se refiere el parrafo antérior,se presentarán planos y memorias técnicodescriptivas ante la Secretaría de Economía,como sigue:

SISTEMAS DE DISTRIBUCION.-Se presentarán planos y memorias técnicodescriptivas para las instalaciones iniciales, las ampliaciones solamente requerirán dichos planos y memorias cuando sean de tipo de construcción distinto del que ya haya sido aprobado al interesado para la misma zona.

INSTALACIONES OCULTAS.-Para las instalaciones ocultas,incluyendo,las de los usuarios de energía eléctrica,se presentarán planos,antes de la ejecución.

La Secretaría de Economía podrá requerir de los interesados las aclaraciones,cálculos,datos y modificaciones que estime pertinentes para la aprobación de los planos y memorias técnodescriptivas.

El hecho de que una instalación eléctrica haya sido aprobada,no exime a su propietario ni a quién la utilice de la obligación de corregir defecto o deficiencia que signifique peligro a personas o a la propiedad,y que no hubiera sido notado en el estudio de los planos y memorias técnodescriptivas o en la inspección que haya dado origen a la aprobación.

REQUISITOS CON LOS QUE DEBEN CUMPLIR LOS PLANOS.

REQUISITOS GENERALES.-Para los cálculos y datos numéricos del proyecto se usará el Sistema Nacional de Unidades de Medidas.

Se presentará un calca en tela de cada plano y una copia heliográfica en tela,del mismo,en hojas cuya s dimensiones serán de 70 por 110;55 por 70;35 por 55;28 por 40 ó 21.5 por 28 cm.,debiéndose dejar un margen de 5 cm.en el lado izquierdo de cada plano de las tres primeras medidas y no menor de 2 cm. en los planos de las dos últimas medidas,se exceptúan de ésta disposición los planos de instalaciones ocultas.

En cada plano habrá un espacio libre no menor de 10 por 20 cm., para poner las notas de aprobación.

Se deberá elegir una escala tal que el dibujo de suficiente detalle.

LINEAS SUBTERRANEAS.-Los planos de conjunto de líneas subterráneas tanto de transmisión como de distribución, se presentarán en hojas de 70 por 110 cm., usando escalas de 1:100 hasta 1:2000, y se consignarán en ellos los siguientes datos:

- -Longitud de la línea, puntos terminales de ésta, nombre de las calles por donde pasa, y nombre de las que cruce.
- -Distancia entre los pozos de visita, de inspección manual, y de transformadores.
- -Voltaje de la línea.
- -Número, calibre y material de los conductores y corriente máxima para la que estén destinados.
- -Aislamiento de los conductores, armadura del cable, clase y diámetro del mismo.

Además de los datos anteriores, se deben presentar, ya sea en hojas por separado o en los mismos planos, los detalles siguientes.

- -Corte seccional de los ductos, con las acotaciones necesarias que fijen su posición con relación al lugar donde se vayan a colocar, indicando las dimensiones de su revestimiento.
- -Corte seccional de los pozos de visita, de inspección manual y para transformadores, indicando sus dimensiones y el material que se proyecta emplear, para éstos detalles se usarán escalas de 1:10 hasta 1:50.

INSTALACIONES OCULTAS.- Las instalaciones ocultas se mostrarán en dos copias de planos de la planta de cada uno de los pisos del edificio en que se vaya a hacer la instalación oculta, consignando los siguientes datos.

- -Diámetro de la tubería, dimensiones de otros ductos y su tipo.
- -Número de conductores en cada tubería o ducto.
- -Calibre y clase del aislamiento de los conductores.
- -Número y capacidad de los circuitos.
- -Localización de cajas de conexión, contactos, apagadores, salidas para alumbrado, etc.
- -Tabulación de los signos convencionales que se usan en el plano.

CALIBRES DE LOS CONDUCTORES.-Cuando se dan números de calibre de conductores, dichos números corresponden al Sistema Norteamericano de Calibres(A.W.G.), a menos que se haga referencia expresa a otro sistema de numeración.

CONDUCTORES.-Los conductores a que normalmente se hace referencia son de cobre. Cuando no lo sean, se indicará su material.

INSTALACIONES EN LUGARES IMPROPIOS.-Los conductores o equipos no deberán localizarse en lugares húmedos o mojado o donde estén expuestos a gases, humos, vapores, líquidos u otros agentes que tengan efectos deteriorantes, ni donde es tén expuestos a temperaturas excesivas,a menos que estén construídos para cada condición especial de instalación.

RESISTENCIA DE AISLAMIENTO.-
Para circuitos que operen a menos de 750 volts.entre conductores,con alambre del # 14 ó # 12,1,000,000 ohms.Para circuitos con alambre #10 ó de mayor sección,la resistencia de aislamiento se basa sobre la corriente permisible en los conductores.Como sigue:

25	a	50	amperes	250,000	ohms.
51	a	100	"	100,000	"
101	a	200	"	50,000	"
201	a	400	"	25,000	"
401	a	800	"	12,000	"
más	de	800	"	5,000	"

MARCAS.-El nombre del fabricante,la marca de la fábrica ó algún otro símbolo de identificación de fabricante y el número de autorización de la Secretaría de Economía,deberán aparecer en todo equipo eléctrico.

MOLESTIAS O PERJUICIOS A TERCEROS.-las instalaciones deberán hacerse de manera que elefuncionamiento del equipo de un servicio no produzca molestias o perjuicios de importancia a otros serviocios o instalaciones,como pueden ser variaciones fuertes de voltaje.
Se recomienda tomar la s precauciones necesarias para instalar y conservar el equipo y las líneas eléctricas de manera que no se produzcan descargas u otros efectos que puedan producir interferencias en la radiorrecepción.

APAGADORES OCULTOS.-Los apagadores instalados en caja m metálica no conectados a tierra y empotradas donde puedan ser alcanzados desde el piso o superficies metálicas,deberán tener tapas de material aislante e incombustible.

APAGADORES VISIBLES.-Los apagadores que se usen en canalizaciones visibles deberán colocarse en zócalos de material aislante que separen a los conductores por lo menos 10 milímetros de la superficie sustentadora.

PANTALLAS Y CUBIERTAS COMBUSTIBLES.-Deberá dejarse un espacio adecuado entre las lámparas y las pantallas u otras cubiertas de material combustible.

El equipo que se use en sistemas de alumbrado de descarga eléctrica y que esté construído para un voltaje a circuito abierto de 1,000 volts o menos,deberá ser de un tipo apropiado para tal servicio.Las terminales de una lámpara de descarga eléctrica deberán considerase como vivas,si cualquiera de ellas están conectadas a más de 300 volts a tierra.

EQUIPO DE CORRIENTE DIRECTA.-Las unidades de alumbrado mencionadas deberán instalarse en circuitos de corriente alterna únicamente, a menos que estén provistas de equipo auxiliar y resistencias especialmente construídas para funcionar con corriente directa y que así se indique en las mismas unidades.

VOLTAJES PERMITIDOS EN CASAS HABITACION.-Solamente se permite usar en casa habitación equipo que tenga un voltaje a circuito abierto menor de 1,000volts, y siempre que cuando se tenga un voltaje a circuito abierto de más de 300 volts, el equipo esté construído de tal modo que no tenga partes vivas descubiertas cuando las lámparas estén en su lugar, ni cuando se retiren.

MONTAJE DE UNIDADES DE ALUMBRADO.-Las unidades de alumbrado que tengan reactores o transformadores, deberán instalarse de tal modo que ningún material combustible quede expuesto a una temperatura mayor de 90°C.

APAGADORES.-Los apagadores deben cumplir con las recomendaciones antes citadas(Apagadores ocultos, Apagadores visibleS).

Reglamento de Construcción del D.F. (Restricciones)

RESTRICCIONES FUNCIONALES, TECNICAS Y ESTETICAS DEL REGLAMENTO DE CONSTRUCCIONES DEL D.F. A EDIFICIOS.

RESTRICCIONES	ART.
(FUNCIONAL) Ningún elemento situado a menos de 2 m. de altura podrá sobresalir del alineamiento.	(21)
(ESTETICO) Las construcciones ubicadas en zonas típicas, calles ó plazas donde existen construcciones declaradas monumentos, deberán armonizar con el ambiente general.	(48)
(FUNCIONAL) Toda edificación con piezas habitables, excluyendo los servicios que esten a una altura mayor de 13 m. sobre el nivel de la acera, deberán tener por lo menos, un ascensor.	(53)
(FUNCIONAL) Ningún punto de edificio podrá estar a mayor altura que 1.75 veces su distancia al paramento vertical del alineamiento opuesto de la calle.	(55)
(TECNICO) Las zonas de influencia de los aeródromos, serán fijadas por la Dirección de Aeronáutica Civil y en ellas regirán las limitaciones de altura que fije dicha Dirección.	(57)
(FUNCIONAL) Los edificios deberán tener los espacios sin construir que sean necesarios para lograr una buena iluminación y ventilación.	(58)
(FUNCIONAL) La dimensión mínima de una pieza habitable, será de 2.70 m. y su altura, será cuando menos de 2.30 m.	(61)
(FUNCIONAL) La superficie total de ventanas libres, será por lo menos de un octavo de la superficie del piso de cada pieza y la superficie libre para la ventilación de un veinticuatravo de la misma.	(63)

RESTRICCIONES	ART.
(FUNCIONAL) Dimensiones mínimas de los patios para dar iluminación y ventilación a piezas habitables.	(64)
(FUNCIONAL) Referente a la iluminación artificial. Niveles mínimos de iluminación en luxes.	(65) -(187)
(FUNCIONAL) Ancho mínimo de pasillos 1.20 m., altura mínima de barandales 0.90 m.	(66)
(FUNCIONAL) Los edificios tendrán siempre escaleras que comuniquen todos los niveles, aunque tengan elevadores.	(67)
(FUNCIONAL) Anchura mínima de puertas a la calle 0.90 m.	(68)
(FUNCIONAL) Suministro de agua potable por habitante 150 lts.	(70)
(FUNCIONAL) Cada una de las viviendas de un edificio deberá tener sus propios servicios de baño, lavabo, excusados y fregaderos.	(71)
(FUNCIONAL) Las aguas pluviales que escurran por los techos y terrazas, deberán ser conducidas al drenaje,	(72)
(FUNCIONAL) Especificaciones para escaleras: Ancho mínimo 1.20 m. Ancho máximo 2.40 m. Huella mínima 0.28 m. Peralte máximo 0.18 m. Servicio de áreas de planta por escalera según su anchura: Hasta 700 m2. 1.20 m. de 700 a 1,050 m2. 1.80 m. de 1,050 a 1,400 m2. 2.40 m.	(78)
(FUNCIONAL) Sobre los servicios sanitarios: Por cada 400 m2. ó fracción, se instalará un excusado y un minguitorio para hombres. Por cada 300 m2. ó fracción un excusado para mujeres.	(80)

ARTICULO 182.- NIVELES DE ILUMINACION.

Los niveles mínimos de iluminación en luxes serán los siguientes:

I.- Edificios para habitación.

Circulaciones.	100

II.- Edificios para comercio y oficinas.

Circulaciones.	100
Vestibulos	300
Oficinas	400
Comercios	300
Sanitarios	100
Elevadores	100

III.- Edificios para la educación.

Circulaciones	100
Salones de clase	400
Salones de dibujo	600
Salones de costura	900
Sanitarios	100

IV.- Instalaciones deportivas.

Circulaciones	100
Sanitarios	100

V.- Baños.

Circulaciones	100
Baños y sanitarios	100

VI.- Hospitales.

Circulaciones	100
Sala de espera	200
Sala de encamados	60
Consultorios	400
Sanitarios	100

. . . 2

VII.- Industrias

Circulaciones	100
Sanitarios	100
Comedores	200

VIII.- Salas de espectáculos.

Circulaciones	100
Vestíbulo	200
Salas de descanso	50
Sala durante la función	1
Sala durante los intermedios	50
Emergencia en la sala	5
Emergencia en las circulaciones	10
Sanitarios	100

IX.- Centros de reunión.

Circulaciones	100
Cabarets	30
Restaurantes	100
Cocinas	200
Sanitarios	100
Emergencia en la sala	5
Emergencia en las circulaciones	10

X.- Edificios para espectáculos deportivos.

Circulaciones	100
Sanitarios	100
Emergencia en circulaciones	10

XI.- Templos.

Altar y retablos	600
Nave principal	100
Sanitarios	100

XII.- Estacionamientos.

Entrada	300
Espacio para circulación	100
Espacio para estacionamiento	50
Sanitarios	100

Restricciones
Legales S. S. A.

SECRETARIA DE SALUBRIDAD Y ASISTENCIA

RESTRICCIONES LEGALES.

RESTRICCION	ART.
Muros macizos exteriores expuestos a la interperie. Espesor mínimo 15 cms.	(21)
Muros y techos expuestos a interperie, de madera ó material laminado, deben ser dobles separados 5 cms. cada uno.	(21)
Juntas de muros y techos arreglados para impedir el paso del aire y agua y protegido de los roedores.	(22)
Los muros de las cocinas y baños deben tener un recubrimiento hasta una altura de 1.50 de un material resistente, impermeable y fácilmente aseable.	(25)
La pendiente mínima en la cubierta de las azoteas será de 1.5%	(26)
Por cada 100 m2 de azotea en proyección horizontal se necesita una bajada pluvial de 7.5 cm. de Ø ó área equivalente. (por lo menos).	(27)
Para desaguar marquisinas diámetro mínimo de 5 cms. ó área equivalente, para superficies hasta 25 m2. (máx.)	(27)
Los techos planos ó inclinados deberán llevar canales colectores y bajadas pluviales cuando el agua pudiera descargar en vía pública ó predios colindantes.	(29)
Las superficies libres de construcción deberán ser pavimentadas ó tener jardín ó ambas. En las pavimentadas deben tener una pendiente mínima de 1%.	(31)
Los pisos de baños, cocinas y pasillos se construirán con material impermeble a prueba de roedores.	(32)
Cuando en las construcciones se vaya a emplear un nuevo material ó preparaciones distintas a las conocidas y aceptadas, deberán ser aprobados por las autoridades sanitarias.	(34)
Los pisos de la planta baja de los edificios, deberán construirse 10 cms. más altos que los patios y estos a su vez 10 cms. más altos que el nivel de la acera ó banqueta, salvo en casos especiales en que la topografía del terreno lo impida.	(35)

RESTRICCION	ART.
Los pisos bajos serán protegidos contra la humedad, mediante procedimientos de impermeabilización.	(36)
Las piezas destinadas a habitación, tendrán luz y ventilación directa al exterior por medio de puertas ó ventanas convenientemente distribuídas.	(37)
La superficie de iluminación no será menor de 20% de la superficie de piso de la habitación.	(37)
Las ventanas y puertas tendrán una sección movible de cuando menos 1/3 de los claros de iluminación para renovación del aire.	(37)
La iluminación y ventilación se satisfacerán: de la vía pública, de los patios del edificio ó por diferencia de niveles.	(37)
Para los locales que por circunstancias especiales se les deba suministrar ventilación artificial, se proporcionará por medio de instalaciones mecánicas que garanticen la renovación eficiente del aire. - El movimiento del aire no será superior a 0.25 m./seg. (velocidad media medida a 0.9 m. sobre el piso). La temperatura comprendida entre 17 y 23°C y la humedad relativa entre 30 y 60%.	(38)
Viviendas mínimas. 2 piezas, cocina, baño y patio de servicio.	(39)
Dimensiones mínimas: Pieza habitación: 7.50 m2. superficie. Cocina: 2.50 m. ancho. 2.30-2.80 altura. Cocina: 6.00 m2. superficie. 1.50 m. ancho. Baño: 2.00 m2. superficie. 1.00 m. ancho. Patio: 4.00 m2. superficie. 2.00 m. ancho.	(39)
Instalaciones sanitarias mínimas: Excusado, lavabo, fregadero, regadera, lavadero.	(39)
Recámaras ó dormitorios mínimos según el número de habitantes. 3 habitantes: 1 recámara. 5 habitantes: 2 recámaras. 7 habitantes: 3 recámaras.	(41)

RESTRICCION	ART.
Para viviendas de más de 3 recamaras 2 habitantes más por recámara adicional.	
Dimensiones mínimas de los patios que sirven para dar iluminación y ventilación con respecto a la altura de los muros que los limiten: Altura hasta. — Dimensión mínima. 4.00 m. — 2.50 m. 8.00 m. — 3.25 m. 12.00 m. — 4,00 m. Para alturas mayores la dimensión mínima será de 1/3 de la altura. En el caso que sirvan para cocinas y baños se reduce a 1/5.	(42)
Queda prohibido dar luz y ventilación a las habitaciones abriendo ventanas o colocando dispositivos con el mismo fín hacia predios colindantes.	(42)
Los edificios de departamentos de más de 5 niveles, deberán contar con ascensor para personas, además de escaleras.	(43)
Todos los departamentos deberán desembocar a pasillos que conduscan a las escaleras, Ancho mínimo de 1.20 m.	(44)
No deberán estar ligadas las escaleras de los niveles superiores con las de los sótanos.	(45)
Ancho mínimo de las escaleras de 1.20 m. para edificios de habitación multifamiliares y de 0.90 m. para unifamiliares.	(45)
La huella neta de los escalones no será menor de 25 cm. y los peraltes no mayores de 18 cm.	(45)
Toda ventana no podrá tener cristales sino a partir de una altura de 90 cm. sobre el nivel del piso. En casos especiales que se requiera poner cristales hasta el piso se proveerán de dispositivos de seguridad hasta dicha altura.	(46)
Especificaciones para sótanos: Altura mínima de 2.30 m., superficie mínima de 7.50 m2., lado menor de cuando menos 2.50 m.	(48)
Que no exista humedad.	(48)
Que dispongan de luz y ventilación.	(48)
Materiales de construcción a prueba de roedores.	(48)
Ningún punto de un edificio podrá estar a una al-	(49)

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RESTRICCION	ART.
tura mayor de 1.75 la distancia horizontal entre dicho punto y el lindero más cercano de las manzanas vecinas. Se exceptúan los motivos arquitectónicos tales como miradores, torrecillas y otros de escasa importancia y carácter ornamental.	
El apartamiento mínimo de agua potable a los edificios, se calculará a razón de 150 litros por habitante, por día.	(52)
Queda estrictamente prohibido la servidumbre o servicios de agua de un edificio a otro.	(53)
Para evitar contaminaciones en cisternas, no deberán existir tubos de albañal o conductos de aguas negras a menos de 3 m.	(56)
Los depósitos que trabajen por gravedad deberán deberán estar 2 m. más arriba de los muebles sanitarios del último nivel.	(57)
En todo edificio deberá haber cuando menos un excusado e irá aumentando a razón de un excusado por cada 10 personas.	(62)
En los baños donde existan regaderas, ésta deberá estar separada del resto por medio de un reborde de 10 cm. (mínimo).	(63)
Las instalaciones hidráulicas y sanitarias se harán con materiales autorizados por la S.S.A.	
Los albañales deberán estar debidamente protegidos contra la oxidación y el intemperismo al igual que sus juntas.	(74)
Los albañales se harán con tubos de 15 cm. de diámetro interior como mínimo.	(75)
Los albañales se construirán bajo el piso de los patios o pasillos de los edificios. Se permitirán modificaciones.	(76)
Los albañales se instalarán a cuando menos un metro de distancia de los muros. Cuando no se pueda llevar a cabo ésto, la instalación se protegerá de asentamientos, previa autorización.	(78)
Los tubos para conductos desaguadores tendrán un diámetro no menor de 32 cm., ni inferior al de la boca de desague de cada mueble sanitario. Se colocará con una pendiente mínima de 2% para diámetros hasta de 76 mm., para mayores la pendiente mínima será de 1.5%.	(79)

RESTRICCIONES	ART.
Los cambios de dirección de los albañales y las conexiones de ramales, se harán con deflexión máxima de 45°.	(81)
La piezas "T" para conexiones de ramales de bajadas con albañales, sólo se permitirán cuando el cambio de dirección sea vertical a horizontal.	(82)
Los albañales tendrán una pendiente no menor de 1.5%	(83)
Los albañales estarán dotados de registros a distancia no mayor de 10 m. con objeto de limpieza.	(84)
En el lugar inmediato y anterior al cruzamiento del albañal con el límite del predio y la vía pública habrá un registro.	(84)
Los registros para albañales ocultos, tendrán las dimensiones mínimas siguientes: Profundidad hasta 1 m. 40 x 60 cm. Profundidad hasta 2 m. 50 x 70 cm. Profundidad más de 2 m. 60 x 80 cm.	(85)
En cada cambio de dirección se construirá un registro al igual que en cada conexión con ramales.	(86)
Los albañales estarán provistos en su origen de un tubo ventilador de 5 cm. de Ø como mínimo.	(87)
Queda prohibido el sistema de gárgolas ó canales que descarguen a chorro desde las azoteas.	(91)
Cuando el mismo tubo ventilador sirva para varios excusados, colocados a diferentes alturas, se ligarán los sifones entre sí por medio de un tubo de 38 mm. de Ø.	(98)
Sólo podrá autorizarse la instalación de fosas sépticas ó plantas de tratamiento en edificios ubicados en lugares fuera del perímetro de las redes de saneamiento.	(106)
Toda fosa séptica ó planta de tratamiento será de material y capacidades aprobadas por las autoridades sanitarias.	(106)

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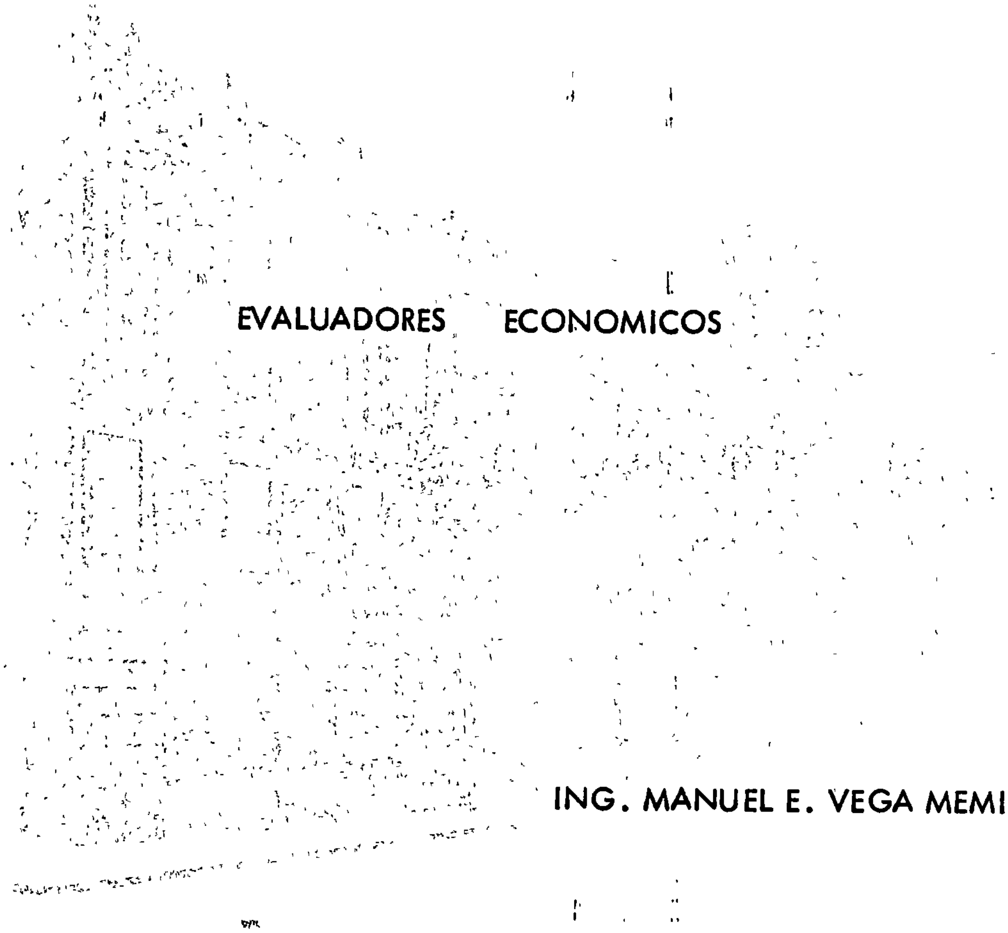

EVALUADORES ECONOMICOS

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SALON C-11
C.F.E.

CENTRO DE EDUCACION CONTINUA

ING. MANUEL E. VEGA MEMIJE.

EVALUADORES ECONOMICOS.

EJEMPLO:

Se requiere evaluar la posibilidad de construir un edificio departamental de 5 niveles, donde la planta baja se dedicaría a locales Comerciales.

Los datos considerados son los mas benéficos, los cuales se obtuvieron después de haber analizado las posibilidades optimistas y pesimistas.

Se ha supuesto, que tanto los INGRESOS como los EGRESOS, sufren un incremento promedio cada 5 años.

La vida económica del edificio se ha considerado de 20 años.

Tasa de actualización del 5%, 10% y 15%.

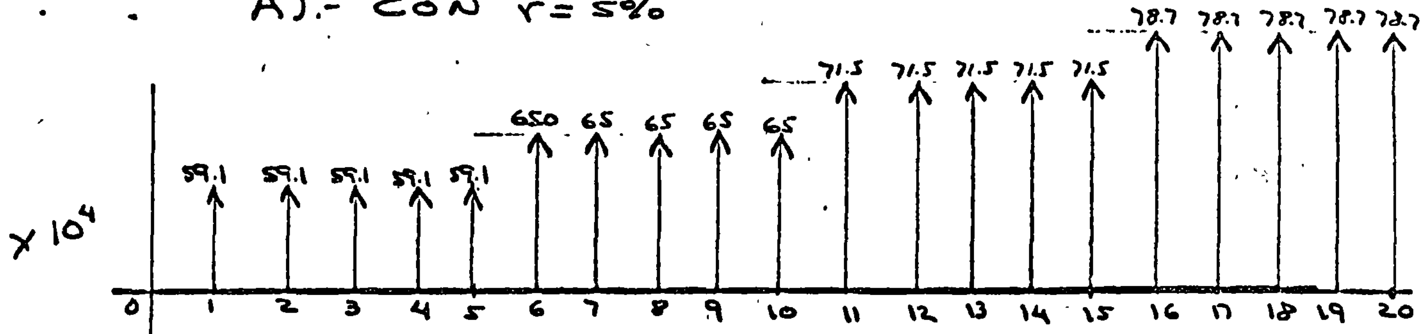
INGRESOS

CONCEPTO	RENTA MENSUAL ($)	AÑOS 1 a 5	6 a 10	11 a 15	16 a 20
Renta departamentos.	40,000.00	480,000.00	528,000.00	580,800.00	638,880.00
Renta locales.	6,000.00	72,000.00	79,200.00	87,120.00	95,832.00
Anuncios.	2,000.00	24,000.00	26,400.00	29,040.00	31,944.00
Estacionamiento.	1,250.00	15,000.00	16,500.00	18,150.00	19,965.00
TOTAL	49,250.00	591,000.00	650,100.00	715,110.00	786,621.00

EGRESOS

CONCEPTO	GASTO MENSUAL ($)	AÑOS			
		1 a 5	6 a 10	11 a 15	16 a 20
Luz	800,00	9,600.00	12,000.00	14,400.00	18,000.00
Agua	4,000.00	48,000.00	54,000.00	60,000.00	63,600.00
Impuestos	2,000.00	24,000.00	30,000.00	33,600.00	36,000.00
Consevación y mantenimiento.	2,000.00	24,000.00	60,000.00	120,000.00	180,000.00
Vigilancia	3,000.00	36,000.00	60,000.00	84,000.00	108,000.00
Administración.	2,000.00	24,000.00	36,000.00	45,600.00	54,000.00
TOTAL	13,800.00	165,600.00	252,000.00	357,600.00	459,600.00

A).- CON $r = 5\%$



$\frac{59.1}{0.23} = 257$

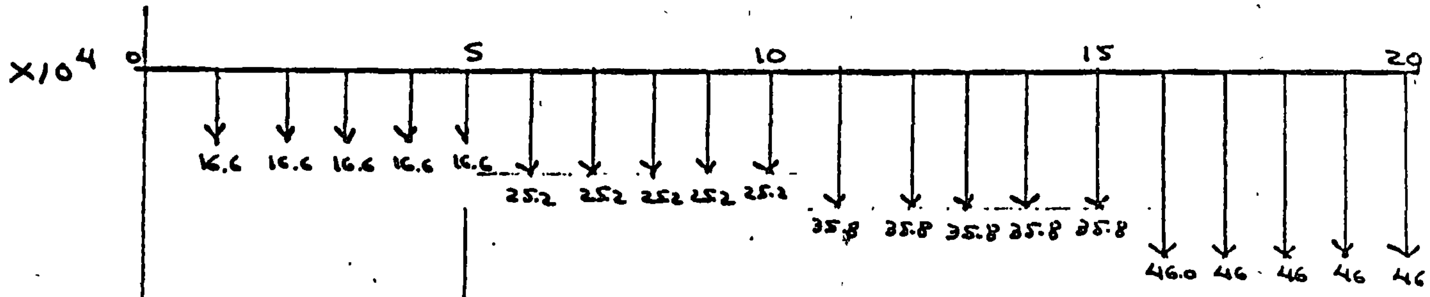
$\frac{65.}{0.23} = 282.6$

$\frac{71.5}{0.23} = 310.9$

$\frac{78.7}{0.23} = 342.2$

$$\left.\begin{array}{l} 342.2 \times 0.48 = 164.26 \\ 310.9 \times 0.61 = 189.65 \\ 282.6 \times 0.78 = 220.43 \\ 257 \end{array}\right\} 831.34 \times 10^4$$

EGRESOS



$\frac{16.6}{0.23} = 72.2$

$\frac{25.2}{0.23} = 109.6$

$\frac{35.8}{0.23} = 155.7$

$\frac{46}{0.23} = 200.0$

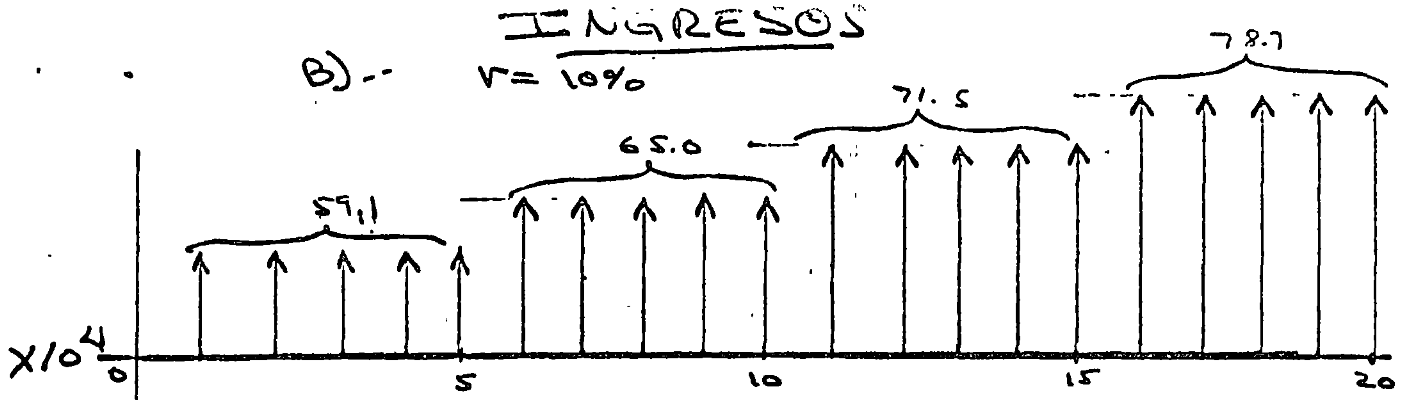
$$\left.\begin{array}{l} 72.2 \\ 109.6 \times 0.78 = 85.49 \\ 155.7 \times 0.61 = 94.98 \\ 200 \times 0.48 = 96.00 \end{array}\right\} 348.67 \times 10^4$$

$$B-C = 831.34 \times 10^4 - 348.67 \times 10^4 = 482.67 \times 10^4$$

$$B/C = 831.34 \times 10^4 / 348.67 \times 10^4 = \underline{2.38}$$

INGRESOS

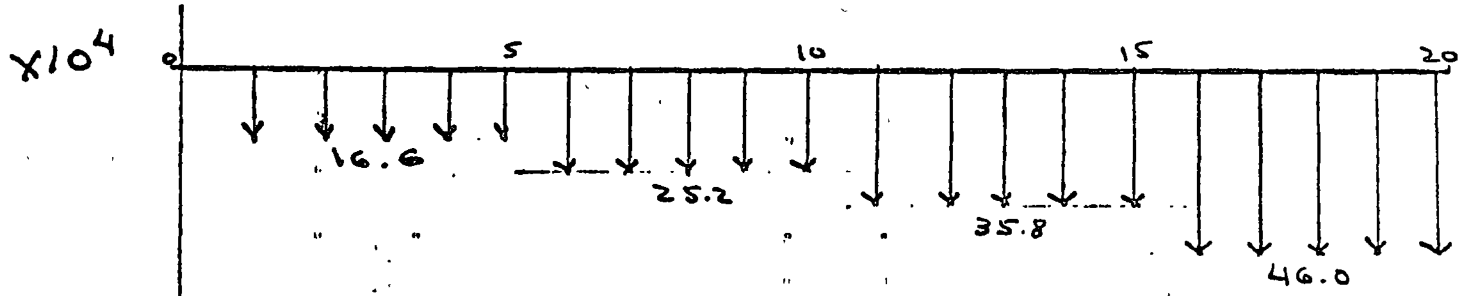
B).- $r = 10\%$



$\frac{59.1}{0.26} = 227.3$ | $\frac{65}{0.26} = 250.0$ | $\frac{71.5}{0.26} = 275.0$ | $\frac{78.7}{0.26} = 302.7$

$$\left.\begin{array}{l} 302.7 \times 0.24 = 72.65 \\ 275 \times 0.38 = 104.50 \\ 250 \times 0.62 = 155.00 \\ 227.3 \end{array}\right\} 559.45 \times 10^4$$

EGRESOS



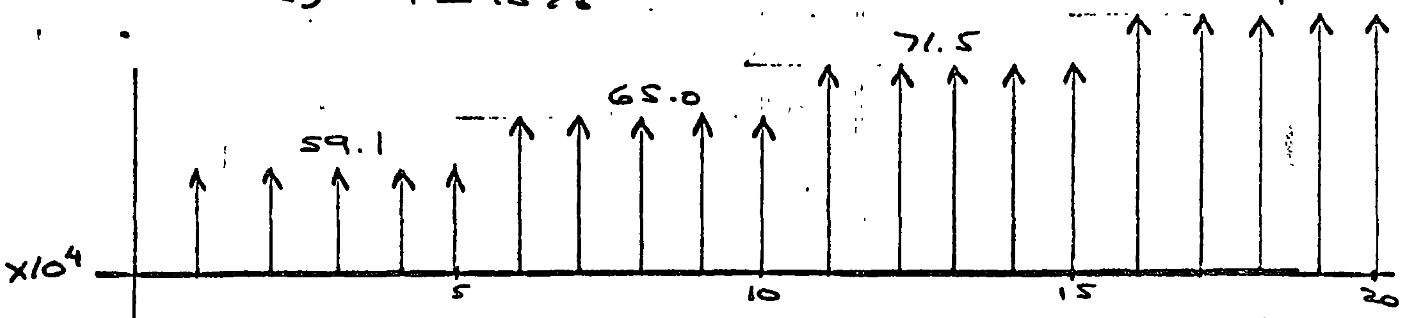
$\frac{16.6}{0.26} = 63.8$ | $\frac{25.2}{0.26} = 96.9$ | $\frac{35.8}{0.26} = 137.7$ | $\frac{46}{0.26} = 176.9$

$$\left.\begin{array}{l} 63.8 \\ 96.9 \times 0.62 = 60.08 \\ 137.7 \times 0.38 = 52.33 \\ 176.9 \times 0.24 = 42.46 \end{array}\right\} 218.67 \times 10^4$$

$B - C = 559.45 \times 10^4 - 218.67 \times 10^4 = 340.78 \times 10^4$

$B/C = 559.45 \times 10^4 / 218.67 \times 10^4 = 2.56$

c).- r = 15%



$\frac{59.1}{0.30} = 197$

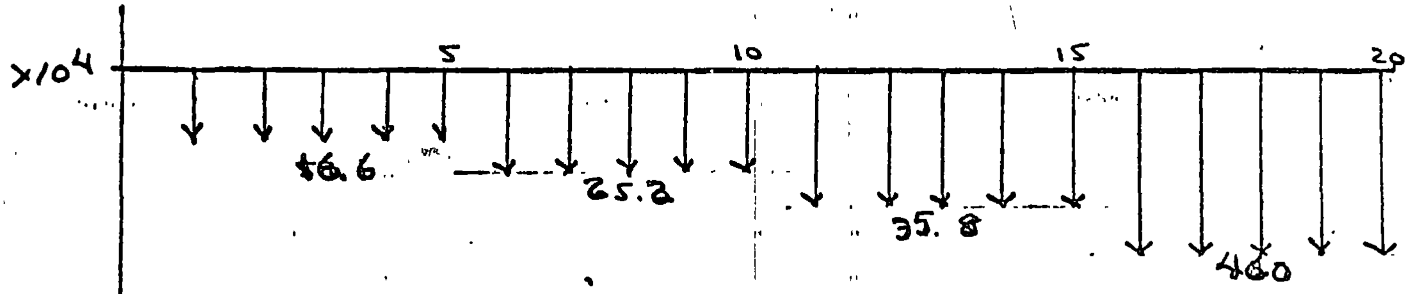
$\frac{65}{0.30} = 216.7$

$\frac{71.5}{0.30} = 238.3$

$\frac{78.7}{0.30} = 262.3$

$$\left.\begin{array}{l} 262.3 \times 0.13 = 34.10 \\ 238.3 \times 0.25 = 59.58 \\ 216.7 \times 0.50 = 108.35 \\ 197.0 \end{array}\right\} 399.03 \times 10^4$$

EGRESOS



$\frac{16.6}{0.30} = 55.3$

$\frac{25.2}{0.30} = 84.$

$\frac{35.8}{0.30} = 119.30$

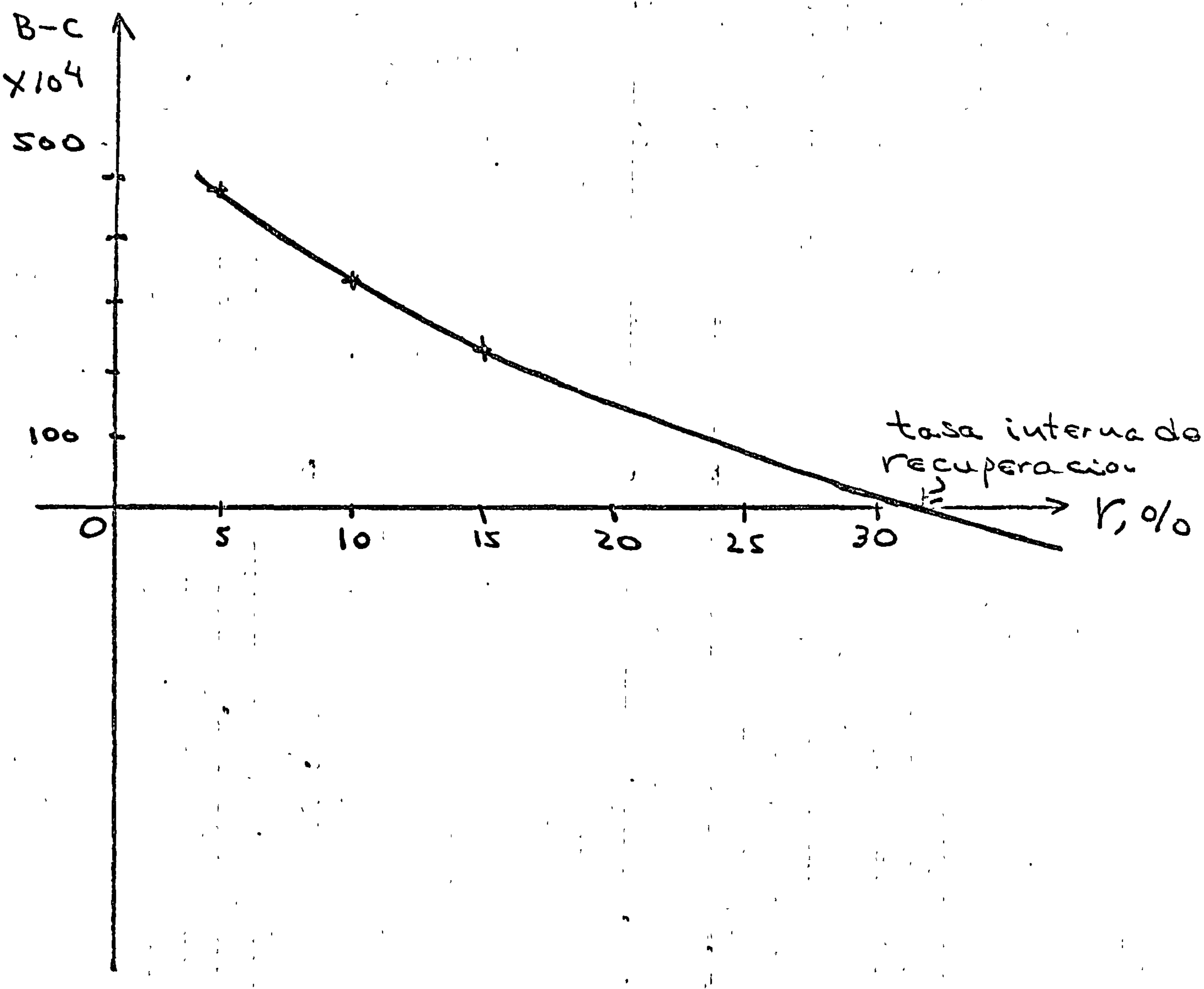
$\frac{46}{0.30} = 153.3$

$$\left.\begin{array}{l} 55.3 \\ 84 \times 0.50 = 42.00 \\ 119.3 \times 0.25 = 29.83 \\ 153.3 \times 0.13 = 19.93 \end{array}\right\} 147.06 \times 10^4$$

$B-C = 399.03 \times 10^4 - 147.06 \times 10^4 = 251.97 \times 10^4$

$B/C = 399.03/147.06 = \underline{2.71}$

TASA INTERNA DE RECUPERACION



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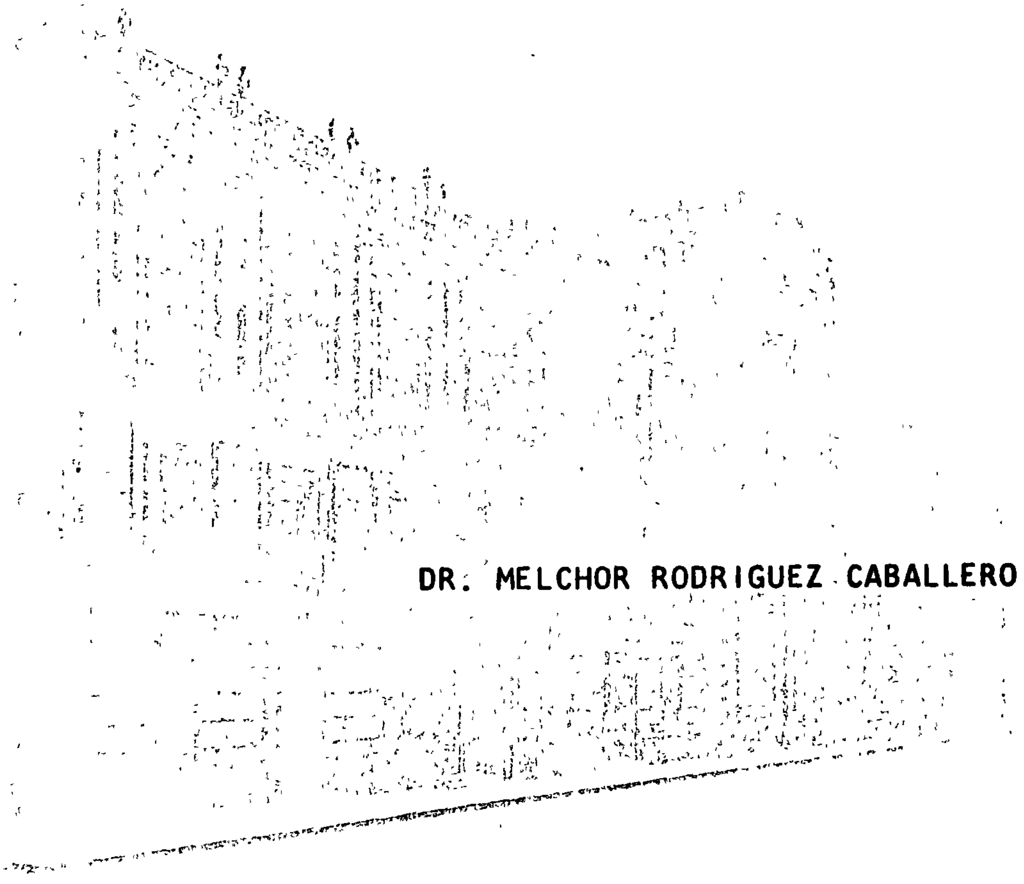

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accessary solution. But the reason that LP can be used is that the criterion of minimax has been built into the system. Minimax does not require expected values and it does not include any provisions for considering probabilities. On the other hand, the solution itself is a risk-type statement specifying the appropriate statistical frequencies that should be employed. For that reason, it might be suggested that such problems should be included with DMUR. Whatever our preference, we must conclude that design decision problems are amenable to formal attack. The classifications of risk, certainty, and uncertainty are helpful but not crucial. For a real decision problem we must deal with a subtle blend. The major issue is to isolate the relevant factors and to avoid forcing them into a standard format just for the sake of using formal methods. The next two chapters will consider some of the difficulties associated with the use of objective methods and will provide a number of practical methods for coping with such difficulties.

REF. 9

chapter 6

QUALITATIVE DECISION METHODS

We have examined the formidable framework that exists for analytical design decision-making. Stripped to essentials we can summarize what has been considered.

(1) Enumeration of design strategies.

(2) Enumeration of states of nature.

(3) Specification of the probabilities for the states of nature.

(4) Determination of outcomes.

([illegible] se of the decision matrix to obtain expected values.

(6) Resolution of decision problems when risk conditions apply.

(7) Several approaches for resolving decision problems under condi of certainty where the expected values derived by risk method used as part of the data input.

(8) A number of criteria that can be employed to resolve dec. problems when conditions of uncertainty apply.

(9) The fundamental character of decisions that are affected by c petitive factors.

In our discussions we have side-stepped a number of important ques that seemed more appropriate for the present stage of development. are now obligated to raise and answer these questions.

30. PREFERENCE MEASURES

Several times we have employed the profit function. By so doing avoided situations where a single outcome dimension was not availa Costs, selling prices, sales volume, and other factors could all be conve into dollars–or so we assumed. Unfortunately, this is not always the Many times, confronted with a number of design alternatives, the best we can do is express our preferences (an intermediate variable) for e For example, there are cases where safety is a primary consideration must be included in the analysis. But how do we evaluate the combin of safety and profit? How much safety is equivalent to one unit of pr Another example of this kind of conundrum occurs when weapon sys are evaluated. Profit–at least in its usual sense–is an almost meanin concept. Factors such as fire power and maneuverability must be we against cost and expected obsolescence. Still another instance would b evaluation of alternative designs for surgical instruments, in which cost would have to be weighed against the remedial properties of instruments. Preference embodies such multiple components. It is "s how" a resolution of many factors and an attempt to estimate their c butions to the achievement of the objectives. There is no reason w LP-design-mix formulation could not be used to maximize preferen stead of profit. Similarly, we should be able to resolve a competitive de system where the payoffs are stated in terms of a preference measure. problem that must be solved, however, is how to derive a mean measure of preference.

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[1] Estimates of profit where relationships are unknown and gue [illegible] is used are no more than preference measures, but the dollar dimension lend [illegible] ar of authe that must be viewed with suspicion.

31. RANKING AND TRANSITIVITY

The qualitative operation of ranking designs is frequently used. Sometimes it works, but often it does not. The major reason for failure is the violation of *transitivity*. Thus, if the designer prefers A to B, B to C and C to A the consistency of logical choice has been abused. Transitivity is obviously required if we are to believe in rank ordering. Too frequently, it can be shown to have been violated. Why is this so?

One basic reason is that multiple dimensions exist which share importance because the objectives are also multiple and tend to oppose each other. The designer would like to use a superior material but he is obliged to work within a limited cost structure. As the seating capacity of a plane is increased the amount of fuel it can carry is decreased. With improvement in the tone of a radio the size of the unit increases. Examples are legion. If all of the objectives cannot be merged into a single-dimensioned objective, such as profit, it is easy to see how comparisons between pairs of designs might accent different components of the objectives. The issue really comes to a head when we bring up the subject of *quality*. This is a term that is commonly used by all participants in the design decision process. But does everyone mean the same thing when the word is used?

32. QUALITY

No treatment of design decisions would be satisfactory if it ignored the problem of defining the quality of a design and the way in which design quality enters into comparisons between alternative strategies. First, let us note that the subject of quality is not independent of such basic considerations as the optimal product or design-mix. Neither is it independent of the competitor effect. As a matter of fact we are viewing quality estimates as the equivalent of preference. This seems to be totally consistent with the prevailing attitude of design decision makers. Therefore, if we can develop relevant quality measures, we can employ these as the outcomes for our decision processes.

What is quality? It is not easy to define. There are two interpretations which are frequently interchanged in both ordinary conversation and technical discussion. Sometimes it is taken to mean that a *desired* characteristic or set of characteristics is embodied in a given product. In this case it is used to impute value. When the statement is made that x is a quality product, it is understood that "high" quality is meant.

On the other hand, a quality is an attribute or property. When used in this latter sense, it is free of value judgment. We will use quality in this second way. When the first meaning is intended, we will specifically state the degree to which the property is considered to be desirable in terms of some standard. Our purpose in doing this is to avoid the unconscio priori judgment of the acceptability of a particular characteristic specific design. It may be true that hand-cut glass is a mark of high qua to some people, but not necessarily to all people. A real leather briefc may be called high quality by a group whose tastes are predisposed aga the "ersatz"–the synthetics and the plastics–but this is neither a final an unequivocal judgment. A large class of attributes (such as color user's prestige) are judged to be of high or low quality on the basi *arbitrary standards*. Arbitrary standards have no permanent existenc time and they will differ among cultures, social groups, and individu The marketing department is usually entrusted with the problem of termining these standards. There are many examples of arbitrary qu standards. High quality is frequently attributed to a high-priced prod even though that product is identical to a lower-priced product mark with a different label. Scarcity is another condition which frequently e the appellation of high quality. But these judgments are not univers accepted and the standard must be called arbitrary.

Fundamental quality standards, on the other hand, are unchanging, b over time and among cultures. They can be traced to physiological requ ments of the human body, basic instincts which characterize human and environmental needs which logically compel agreement among individuals. Thus, if a radio is so designed that all transmitted sounds distorted, there will be universal agreement that the quality of so reproduction is poor. If the handle of a pot always burns the hand of holder, there will be no dispute about the quality level of this featur the design. Fundamental quality standards require agreement on the of those evaluating the quality level as to the objectives of the design the needs to be fulfilled. Once this agreement has been reached, no fur disagreement should ensue. To illustrate this point, if a soap is intende clean effectively when used in a washing machine, once there is concurr on the definition of "clean effectively," all individuals–with or wit washing machines–will agree in their quality judgments. It is possib achieve almost complete agreement on such definitions–hence, the a lation: fundamental quality standards.

The distinction between arbitrary and fundamental standards ca useful when the elements of designs are being classified for evaluation poses. It is not always obvious how to categorize an element. Sometim is apparent that both arbitrary and fundamental standards apply. example, consider the problem of defining aesthetic standards. Alth there is an important physiological component[2] there can be no doubt appearance design factors are hardly universal, nor are culture and invariant. Measurement of aesthetic qualities and the determinatio

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[2] The operation of the perceptors if nothing else.

etic standards are rooted in the psychodynamics of a culture, but they constrained by human structure.

These remarks on quality can be amplified in many ways and a great ery of examples can be drawn to support the major points which we are ng to establish, namely:

1) The quality of a design is a function of some set of standards.
2) If the standard is a fundamental one, then there is universal agreement. Such standards are usually time-invariant.
3) If the standard is an arbitrary one, then quality evaluations can and will change over time in some logical fashion. The process of change is a random one yet consistent within its own framework.[3] A technological break-through opens up new design possibilities and can alter previous standards.
4) Arbitrary standards are not only different over time, they are also different at any given point in time among individuals, groups, and cultures. Thus, there is a need to consider demographic and psychological stratification of consumers–a marketing function.
5) A great number of quality judgments must be rendered for each design. While the judgments will not be independent of each other they will not unanimously infer high quality to all properties of one design. Some attributes will be more important than others. One high quality can outweigh a score of low qualities in the same product design.

must therefore find a means to accomplish the following:

1) We must be able to measure the quality level of each characteristic in a product. This requires the determination of a standard for each characteristic.
2) We must be able to combine the separate judgments rendered for each characteristic in order to produce a resultant measure of quality.
3) The resultant quality measure should express our preference for each design alternative. It should be immune to violations of transitivity.

RESULTANT QUALITY

We shall begin in a simple way by using a very common method of aluation that is totally wrong. Our intention is to compare designs *A*

The process is of the Markov type, where the state at time t is a function of the e at time $t - 1$. The rules for transition may be quite complex and the number of ble states may be very great indeed. All possible states will seldom be enumerable– y of them are hidden until they are discovered by creative insight.

and *B*. By agreement two characteristics are isolated as being the major determinants of quality and therefore preference (and therefore attainment of the objectives). We shall call these characteristics 1 and 2. The quality of each design is rated with respect to the two characteristics. Thus A_1 is the quality evaluation of design *A* with respect to the first characteristic; similarly B_2 is the quality evaluation of design *B* with respect to the second characteristic. By switching from the analysis of the design as a whole to the analysis of each design characteristic, the dimensional difficulties that are inherent in over-all evaluation can be avoided. Consequently, violations of transitivity can be eliminated.

Next a set of weighting factors is chosen. Individuals of the design team may not agree on the assignment of weights. For that matter, there will probably not be complete agreement on the quality standards and measures that are to be employed. At least all such disagreements can be discussed because they are objective (although qualitative). We will return to this subject again. But first let us see what is done with the weighting factors and what is wrong with the method that is commonly employed.

Let the weights be w_1 for the first characteristic and w_2 for the second characteristic. Then the quality of design *A* is given as, $Q_A = w_1A_1 + w_2A_2$, and the quality of design *B* is, $Q_B = w_1B_1 + w_2B_2$. This is what is done in those circumstances where extra effort is being expended and where formal qualitative (quasi-quantitative) methods are allowed. We shall uncover the fundamental error that is being made by taking a specific example. We will compare the qualities of two boxes, each of which contain one apple and one orange.[4] To begin, let us assume that a highly-skilled fruit grader determines the following: Box *A* contains an apple of grade 2 and an orange of grade 5, where 5 is the best possible grade and 1 is the lowest grade. Box *B* contains an apple of grade 4 and an orange of grade 3. One of the designers of the box of fruit states that in his opinion the contributions of the apple and the orange to the over-all quality of the combination are equivalent. By this he means that his preference for either one of the boxes will be equally influenced by both types of fruit. The implicit assumption is made that he is not speaking about his own preference. Instead he is attempting to mirror the consumers' attitude and make his preference equivalent to the profit potential of each type of box. Then, at least for this decision-maker, the quality measures would indicate equal quality evaluations for both boxes. Thus:

$$Q\,(\text{Box } A) = (1)(2) + (1)(5) = 7 \quad \text{and} \quad Q\,(\text{Box } B) = (1)(4) + (1)(3) = 7$$

We are not going to quarrel with the choice of weights. Market surveys could be conducted to lend support or contradict the contentions that they

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[4] The characteristics of the design (box of fruit) are, characteristic 1: apples; characteristic 2: oranges.

nt. Neither shall we disagree with the quality evaluations of the
. Presumably, he is a sensitive measuring instrument. If one doubts
second grader can be obtained and the test procedure replicated.
the reliability of our first grader has been authenticated we can relax
s point. The relationship of the grades themselves to the consumers'
ation of quality is another traditional area for dispute, but here too
ognize that market surveys can be employed to lend credance to
rading system. We find something else objectionable–namely, the
dure that has been used.

IMENSIONAL ANALYSIS

t us determine the dimensions of the quality measure that was ob-
d above. We have added apples and oranges and our result is ex-
ed in these terms. But what does the dimension *apples plus oranges*
? The answer is: "nothing we can understand." Let us underscore this
usion by considering another example. Assume that two designs are
evaluated in terms of their cost, size, and weight. The objective for
of these characteristics is to obtain the minimum value. (The objective
he fruit box was a maximum value.) Assume the following data:

	Cost	*Size*	*Weight*
Design C	$3	12"	1#
Design D	$2	24"	2#
Importance	5	2	3

g the incorrect method we obtain:

$$Q\ (\text{Design } C) = 5(3) + 2(12) + 3(1) = 42\ (\text{dollars} + \text{in.} + \text{lb})$$

$$Q\ (\text{Design } D) = 5(2) + 2(24) + 3(2) = 64\ (\text{dollars} + \text{in.} + \text{lb})$$

gn *C*, having a smaller evaluation number, is the indicated choice.
, let us transform inches to feet. If the method of evaluation were
ct, then Design *C* would continue to be preferred, since there could
o logical basis for using an inch scale instead of a foot scale. We have:

$$Q\ (\text{Design } C) = 5(3) + 2(1) + 3(1) = 20\ (\text{dollars} + \text{ft} + \text{lb})$$

$$Q\ (\text{Design } D) = 5(2) + 2(2) + 3(2) = 20\ (\text{dollars} + \text{ft} + \text{lb})$$

lesigns are now reported to be equivalent. Apparently this method of
ation is not invariant to the scale of our measuring instruments. As
r example let us change dollars to cents. Then:

$$Q\ (\text{Design } C) = 5(300) + 2(1) + 3(1) = 1505\ (\text{cents} + \text{ft} + \text{lb})$$

$$Q\ (\text{Design } D) = 5(200) + 2(2) + 3(2) = 1010\ (\text{cents} + \text{ft} + \text{lb})$$

The preference has now switched to Design *D*. The results are intolerable. This system of evaluation has been discredited by example. Underlying these illustrations are the basic requirements of dimensional consistency. The method used above for comparing alternative designs produces dimensional abominations. How then should we proceed?

We must multiply the quality measures instead of adding them. The weighting factors will be exponents associated with each characteristic. Thus:

$$Q_A = A_1^{w_1} A_2^{w_2} \quad \text{and} \quad Q_B = B_1^{w_1} B_2^{w_2}$$

For the box of fruit this will give:

$$Q\ (\text{Box } A) = (2)^1 (5)^1 = 10 \quad \text{and} \quad Q\ (\text{Box } B) = (4)^1 (3)^1 = 12$$

Since the objective is to obtain the highest number–Box *B* is preferred. With respect to our second example we obtain:[5]

$$Q\ (\text{Design } C) = (3)^5 (12)^2 (1)^3 = 34{,}992\ (\text{dollars} \times \text{in.} \times \text{lb})$$

$$Q\ (\text{Design } D) = (2)^5 (24)^2 (2)^3 = 147{,}456\ (\text{dollars} \times \text{in.} \times \text{lb})$$

Our objective was the smallest number and so Design *C* is preferred. Now let us go through the same set of scale transformations that we previously used.

$$Q\ (\text{Design } C) = (3)^5 (1)^2 (1)^3 = 243\ (\text{dollars} \times \text{ft} \times \text{lb})$$

$$Q\ (\text{Design } D) = (2)^5 (2)^2 (2)^3 = 1{,}024\ (\text{dollars} \times \text{ft} \times \text{lb})$$

This time, Design *C* continues to remain the choice. Lastly,

$$Q\ (\text{Design } C) = (300)^5 (1)^2 (1)^3$$

$$= 2{,}430{,}000{,}000{,}000\ (\text{cents} \times \text{ft} \times \text{lb})$$

$$Q\ (\text{Design } D) = (200)^5 (2)^2 (2)^3$$

$$= 10{,}240{,}000{,}000{,}000\ (\text{cents} \times \text{ft} \times \text{lb})$$

which is also a Design *C* choice.

To understand the nature of what we have done let us find the ratios of each paired comparison. These are, for the method of addition:

$$(1)\ \frac{42}{64} = 0.66 \qquad (2)\ \frac{20}{20} = 1.00 \qquad (3)\ \frac{1505}{1010} = 1.49$$

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[5] For ease of computation this can also be written as:

$$\log Q_C = w_1 \log C_1 + w_2 \log C_2 + w_3 \log C_3$$

d for the method of multiplication:

$$1)\quad \frac{34{,}992}{147{,}456} = 0.24 \qquad (2)\quad \frac{243}{1{,}024} = 0.24 \qquad (3)\quad \frac{243(10)^{10}}{1{,}024(10)^{10}} = 0.24$$

n dimensional terms, the ratio with addition is of the type:

$$\frac{(\text{dollars})}{(\text{dollars} + \text{in.} + \text{lb})} + \frac{(\text{in.})}{(\text{dollars} + \text{in.} + \text{pounds})} + \frac{(\text{lb})}{(\text{dollars} + \text{in.} + \text{lb})}$$

This cannot be further reduced. The ratios derived from multiplication ield a pure number, e.g.,

$$\frac{(\text{dollars} \times \text{in.} \times \text{lb})}{(\text{dollars} \times \text{in.} \times \text{lb})} = \text{pure number}$$

It is conclusive that the multiplication method is the correct approach.[6]

35. A STANDARD FOR COMPARISON

Only ratios have significance when we apply this method to obtain preference measures. Our outcomes are therefore only relative but that is enough for the purposes of choosing one strategy out of a set of possibilities. Thus, for the box of fruit the outcome ratio is:

$$\frac{\text{Box } A}{\text{Box } B} = \frac{10}{12} = \frac{5}{6}$$

and since we want as large a number as possible we choose Box *B*.

When we are trying to obtain outcome values for our decision matrix, the LP product-mix analysis, or the competitive payoff matrix, it is useful to take ratios with respect to a standard. In this case, the best possible design for the box of fruit would be an apple of grade 5 and an orange of grade 5. Using the weighting system previously specified, our ratios with respect to the standard (best possible) design would be:

$$\frac{\text{Box } A}{\text{Standard}} = \frac{5}{25} \quad \text{and} \quad \frac{\text{Box } B}{\text{Standard}} = \frac{6}{25}$$

It is also useful to standardize the weighting system. This is easily accomplished by making the weights sum to one, ten, or one hundred. We used ten for the three-characteristic example. In the case of the box of fruit we could have utilized weighting factors of one half. Changes of this sort will affect the ratio values but the order of preference will remain the same.

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[6] For further discussion of these points see P. W. Bridgman, *Dimensional Analysis* (New Haven: Yale University Press, 1922), pp. 21-22.

One additional characteristic of the multiplication method should be noted. If a mix of objectives exists, then it is necessary to use negative exponents. For example, if we wish to have a minimum of cost and a maximum of strength, we would select the design alternative with the smallest quality evaluation number from the set of such measures:

$$\frac{Q_j}{Q_*} = \frac{(C_j)^{w_1}(S_j)^{-w_2}}{(C_*)^{w_1}(S_*)^{-w_2}} = \frac{(C_j)^{w_1}(S_*)^{w_2}}{(C_*)^{w_1}(S_j)^{w_2}}$$

where C_j is the cost of the *j*th design, S_j is the strength of the *j*th design, and the asterisk represents the standard design.

We now have developed a practical means for assigning outcome values when other approaches cannot be used. A noteworthy benefit of using this procedure is that it forces all participants of the design team to specify the factors that are playing an important part in their own individual thoughts about the problem. First, the critical characteristics must be listed. Usually a master sheet would be drawn up that included every characteristic suggested. If there is disagreement as to what should be included on the list the dispute can be resolved when the weights are assigned. A zero weight produces the value of one, which in effect is equivalent to dropping consideration of the disputed characteristic. The operation of assigning weights is also of great utility since it communicates the attitudes and ideas of each member of the design team. There is no other effective way of achieving the vital understanding that is required if differences of opinion are to be resolved in the company's favor. At the same time, there is nothing at all conclusive about these value judgments. They will differ from individual to individual and frequently can differ for the same individual over a 15-minute period.

Outcome values would be derived for each intersection of the decision matrix. If, for example, the states of nature are by user categories, then a different set of weights would be assigned for each column–depending upon the characteristics that each type of consumer looks for in this product. Once all of the outcome values are supplied, the expected values can be derived and all procedures previously described can be utilized. With respect to the design-mix problem a quality-preference equation, rather than a profit function, would be maximized. For the competitive decision-making system, the payoff measures should express the competitive advantage that a particular combination of strategies would produce. This is the most difficult area with respect to applying the preference measures, but with a degree of ingenuity some headway can be made.

There is no question about it–the measurement problems can be severe, particularly with respect to the arbitrary type of standards. When the fruit grader rated the orange in Box *A* as the best possible grade we recognize that he must have his own criteria. We may not be willing to agree with this fruit grader until we know what rating scheme he is using. He must t out in detail. He obviously employed various values of w by deciding certain qualities of an orange were more important than others. We t that his basic measurements of quality levels are reproducible, but nnot find out until we make him break down the decision-evaluation m that he used. He might have had such categories as: the shape of ruit, the color, the firmness, the size, the weight, and so on. Notice these categories begin to become measurable as they become more led, and a standard for such measurement can be set.

QUALITY CHARACTERISTICS

efore we conclude this chapter let us consider some of the characteristics might normally be involved in a quality evaluation. To begin with, have a set of characteristics which might be called "functional." We l divide the functional characteristics into three classes: (1) efficiency urpose, (2) man-fitness and (3) reliability. We shall discuss them briefly. second major class can be called "nonfunctional" characteristics. se are composed of such factors as appearance, communication of cepts, and timeliness. However, we shall merely mention them. Cerly, there are other ways of grouping factors. No claim can be made t these categories include all possible quality characteristics, but they represent a synthesis that may be helpful. Discussion at this point in newhat more specific terms can also reduce the abstractness which is erent in efficient presentation of method.

Vith respect to our first point, efficiency of purpose, we will find such egories as: speed of action, ability to clean, heat generated, light pro- led, ease of using, clearness of type, and versatility. Each product-type product class has its own particular purposes. It is essentially through nification of these basic purposes that one derives the concept of a duct class. We cannot expect to find a set of characteristics that will rk for all products because the purpose characteristics are the major ining feature of the designs that are being investigated. A point must be de, however: all possible purposes that can be conceived should be set wn at the initial stages in the development of the product design. ually, the designer has these in mind, but seldom is he specifically com- ssioned to create a thing which accomplishes x, y, and z. Purpose should painstakingly detailed. Frequently, an unrecognized use appears for a ven product design at a later time—long after a selected design is accepted d put into production. Such by-products frequently delight the product nagers when in fact they should be conscious of having missed this point ring the developmental stages. Fortuitous events are not to be scorned— r do we intend to give the impression that a creative event after a oduct has been marketed should be subjected to scorn and derision.

Sometimes the by-product appears as a result of a change in the market, and in this case one might ask: "Was this change anticipated?" No matter how operational we get in our approach to the design problem we cannot hope to answer all such questions and we cannot begin to believe ourselves infallible. But the fact remains that in a logical system, most by-product possibilities should have been anticipated, and the dynamics of the market in this regard are at least in part predictable. The prediction may not be a good one. We refer only to the fact that a prediction should have been attempted.

Thus, for a stapler we want to list quality characteristics which include the force required to drive the staple into many different materials. In addition we want to know the force required to drive the staple through various thicknesses of paper. And we include other quality characteristics such as the kinds, sizes, and shapes of surfaces to which it can be applied, the ease of filling, the frequency with which it must be filled, the necessity of keeping the mechanism clean, the ease of cleaning, and so forth. This work may seem exhausting, but it has a very important benefit. It diligently details all of the purpose factors which influence the consumers' judgment of quality. Assuming that the purpose factors are of importance in most consumers' minds, it permits us to approach the problem of evaluating alternative designs in the manner we have described.

Man-fitness was our second sub-category within the functional quality characteristics. Here we are talking about the correspondence of the human form and human abilities to the product characteristics. This subject has been treated at some length in the literature under various names, including human engineering, bio-mechanics, ergonomics, human factors, and engineering psychology. Being dissatisfied with these names, we have coined our own term for this publication hoping that this extravagance will be excused in the light of the proliferation of descriptive names currently in use. Such characteristics as weight, size, handgrip, foothold, seated comfort, comfort in general, readability of dials, clarity and perception of sound, taste, smell, tactile sensations, all play their part in the formation of this category of qualities. These are not primary purposes of the design, but they are accompanying restrictions.

37. THRESHOLDS

Most of these man-fit qualities have *thresholds* below which even the highest quality of purpose fulfillment must be ignored. For example, a pen which writes forever without requiring refilling will not be considered as having a high resultant quality level if writing with it is painful, or if the hand is flooded with ink. The man-fit area is not the only one in which thresholds exist, e.g., soap that soils, a knife that does not cut, a glass that

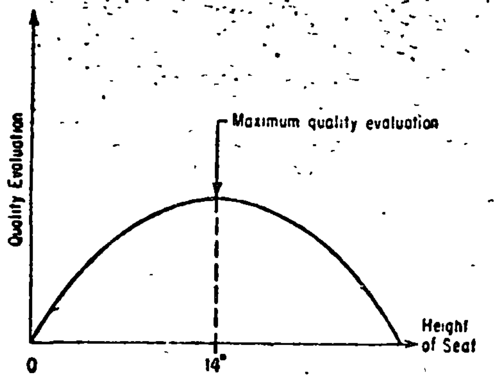

FIG. 36 Evaluation of Quality for Different Seat Heights (for a particular consumer group).

-. In all of these cases, the value w will change when a threshold is :d. Let us consider the comfort of an automobile seat. Assume that for -ticular group of consumers it has an importance of 3 out of a possible points. That is, $w_{seat} = 0.03$. Figure 36 presents a representative curve uality evaluation as a function of the height of the seat. We presume one of the basic similarities of our chosen consumer group is similar t and build. Within a normal range of seat heights, $w_{seat} = 0.03$. ever, at the extremes the contribution of seat height to resultant ity becomes distorted. In fact, the seat becomes the most important r in the consumers' evaluation of the car. These are value thresholds, a possible value function is shown in Figure 37. We must obviously consider such thresholds when we attempt to measure the resultant quality of a design.

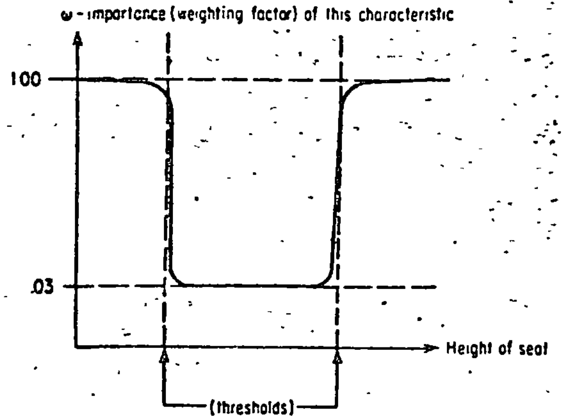

FIG. 37 Value, ω, of Quality Characteristic—Seat Height—Over the Range of Possible Settings.

The contribution of variety in terms of man-fitness can be called functional variety. It is of major importance. Cinderella could not have become a princess if the glass slipper could have fit her step-sisters' feet equally well. Self-fitting materials, such as stretch-socks, are part of a revolution in technology. Children some fifty years hence may judge the Cinderella story to be unreal-so accustomed will they be to self-fitting materials in garments and shoes. Meanwhile, functional variety is an absolute necessity if new segments of a potential market are to be added to the company's over-all potential. This factor can be included in quality evaluation. It is not the same thing as the variety induced by the capacity, product-mix analysis.

Our third functional quality class concerns the reliability of the design. Primarily this refers to the performance of the design over time. One of the major aspects of reliability is total failure. Some products are subject to a gradual deterioration. Others will perform as intended and then suddenly fail. Most products exhibit a combination of these characteristics. A great deal has been written on the subject of failure rates and reliability. Manufacturers' guarantees are significant indicators of the existence of thresholds applicable to this category. Thus, if an automobile fails within the first thirty days or some given number of miles, the consumers' evaluation of the product would weight the importance of this low quality in an extreme fashion. Furthermore, we see from this example that the weighting system may shift over time. Many automobile manufacturers are extending their guarantee period as a result of increasing importance being placed on this characteristic by the consumer. This gives us an example of the dynamic properties of the value system. How can we cope with this aspect of quality? Briefly, we are forced to predict a trajectory for the value or weighting system. Then quality ratios are obtained for different points in time. The means of achieving the forecast are circumscribed by the body of knowledge which presently exists in the subject area.

Our present discussion applies to refrigerators, light bulbs, television sets, and also to bars of soap, tubes of toothpaste, and cans of food. In each case, the life expectation, the degree of variability of the lifetime, and the importance of the lifetime will differ. But in general, the quality evaluation of the lifetime property will increase as the lifetime itself increases. This is a monotonically increasing quality function unlike the inverted U-shape quality evaluation for the height of an automobile seat. For characteristics of this kind the optimal quality is associated with the maximum number of the characteristic. On the other hand, when we consider the degree of drift from a fixed precision level, e.g. observable wear on silver-plated dinnerwear, reduced illumination from aging flourescent bulbs, worn heels and soles on a pair of shoes, and so on, the quality judgment will monotonically e with reasing drift. In this case the objective will be associated the minimum number of the characteristic, zero drift being the highest ty measure.

ere is not very much that we can say explicitly about the nonfunc- al domain. The three functional sub-categories have received extensive eering and scientific study. The required measurements or estimates ot easy to come by, but they can almost always be approached. In the functional area, very little work exists. The reason for the dispro- ionate emphasis is easily understood. The functional categories reflect amental standards for the most part. The nonfunctional region is with shadows and elusive forms. The foundations are almost ex- vely in the realm of arbitrary standards. This has led most serious estigators to shun the nonfunctional quality area. However, the fact ains that by sticking one's head in the sand, one does not avoid the leasant, the dangerous, and the threatening. The nonfunctional quality a is too important to ignore. There is very good evidence that in the ermination of resultant quality nonfunctional categories can play a or role.[7] Nevertheless, it would be inappropriate to do more than stress importance of the nonfunctional categories at this time–and to state t no design analysis can be meaningful that ignores these characteristics. e marketing department can usually enumerate those categories that relevant for any specific time and place. They can also supply the ntial data and estimates. For any specific problem the nonfunctional ain must be included and examined in as objective a fashion as is sible.

This is particularly true with respect to thresholds that operate in this domain. s can be traced to the nonfunctional categories more frequently than to the func- al categories. Also, there is probably no greater condemnation than to label some- g, "out of style."

chapter 7

SIMULATION METHODS

We have developed a variety of analytic methods for resolving product design decision problems. They were presented as much as possible in the context of actual use. Accordingly, Chapter 6 was devoted to practical, qualitative (or quasi-quantitative) means for determining outcomes that could be used in analytic systems. There are times, however, when analytic methods are applicable only in theory. This is frequently the case when complex outcomes must be determined. For example, consider the following problem. A number of alternative designs are on the drawing board for Mach 2 airliners. The flight characteristics of each plane design can be partially determined by using mathematical equations. Models in wind-tunnels are used to fill in some of the missing information. In the last analysis, many critical factors remain unresolved until an actual, full-scale prototype has been constructed and flown under a variety of conditions. Why aren't all of these problems amenable to early analytic solution? The answer is that we do not know enough about the functional relationships between the controllable variables, the noncontrollable variables, and the outcomes.

38. COMPRESSING TIME

Wind-tunnel models and towing-tank models are both examples of concrete, physical representations that are purposefully constructed to interact with a controlled environment. All relevant states of nature are anticipated and a device is built to simulate them. By simulation we mean that a controlled representation of reality is utilized in order to obtain information about the behavior of a system. We use simulation instead of analysis because the system is too complicated to permit *inference* to work. Instead, observation must be used. Sometimes it is more economical to use simulation than analysis. At other times the mathematical equations that describe the system cannot be solved. For these reasons, simulation is particularly well suited to product design problems. The fatigue characteristics of moving parts can usually be derived by laboratory tests. Variations of temperature, humidity, atmospheric conditions, and other relevant environmental variables are easily included in such experiments.

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ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

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CURSO DE PLANEACION Y ANALISIS ECONOMICO DE EDIFICIOS.

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NOVIEMBRE 1974.

El objetivo de esta plática es llegar a establecer claramente cual es la función de cada edificio y de sus interrelaciones dentro del medio urbano, a través del enfoque sistémico.

Parece sencillo a primera vista, el hablar del enfoque sistémico; es algo tan obvio que nos preguntamos el por que se considera tan novedoso y porque no ha sido ya aplicado intensivamente en todos los campos. Es cierto, no es novedoso como posición, ya que en todas las épocas ha habido siempre quien intuya que formamos parte de un gran sistema y que todo acontecimiento o acción tiene un impacto mayor y más sofisticado del que hemos logrado preveer. El problema ha sido siempre el tratar de explicar este fenómeno y de obtener algo que nos sea de utilidad.

En el hombre antíguo las interrelaciones que tenía con otros hombres, con el medio y con el proceso histórico eran más aisladas, ya que no contaba con los medios de comunicación actuales en cuanto a información y movimiento; y por lo tanto le era difícil el analizar hechos y situaciones si no eran como simples consecuencia directa de un acontecimiento existente.

El hombre clasificaba lo que le rodeaba y sucedía dentro de grupos y procesos sencillos que cubrían sus necesidades de información para manejo de su medio ambiente; lo que se salía de esas normas caía simplemente en el campo de lo mágico o lo extraterrenal. Era un proceso en el cual por falta de comunicación(1) el impacto que tenía un hombre o una sociedad

(1) Nota.- En este trabajo se considera que el conocimiento es parte de la comunicación, como interrelación de la verdad física y el hombre.

era siempre limitado; había mucho tiempo entre cada acontecimiento que permitía al hombre asimilar o controlar los cambios y grandes distancias que ayudaban a aislar su impacto.

En la actualidad gracias a la comunicación la dimensión del tiempo y del espacio ha variado si lo medimos por la cantidad y procedencia de las interrelaciones que nos afectan, y nos empezamos a dar cuenta que estamos participando en un proceso que ya no logramos controlar.

Cada día es más evidente el problema de las ciudades como un sistema del cual estamos perdiendo control, no solo en términos de contaminación y sobre población, sino también en términos de integración física, social y cultural.

Esto ha obligado en los últimos años, a cuestionar las bases que heredamos de análisis y control y ha cobrado fuerza una antigua actividad, la actividad de la planeación.

Veamos cual es la situación actual de esta disciplina a nivel mundial. En el marco general es patente la preocupación de varios técnicos en analizar y explicar cual ha sido nuestro proceso de desarrollo socio económico para intentar así, justificar ó atacar los factores que cada uno cree ha hecho inoperante al sistema (centralización, dependencia interna-externa, reforma agraria, industrialización, etc.). En el campo metodológico la idea de perfeccionar las técnicas de elaboración y análisis de proyectos-que había sido uno de los objetivos básicos de muchos años- ha sido insuficiente, pues ha conducido a que en la mayoría de los casos la mejor posibilidad de cuantificación y detección de variables económicas no reflejan todavía desde el punto de vista social, las mejores alternativas. Es muy notorio el hecho de que actualmente entre los planificadores hay dos generaciones con principios distintos; aquella que vé los problemas que van surgiendo como factores más o menos independientes (vivienda, salud, educación, servicios etc. etc.) los cuales hay que ir solucionando para continuar operando eficientemente el sistema establecido, y otro grupo el cual vé los problemas como una serie de manifestaciones de un sistema basado en una desigualdad económica, política y social. Es decir, hay un grupo que no vé solución o planeación posible sino un cambio profundo en nuestros valores y en nuestros principios económicos y otro que vé la planeación como el ir intentando resolver aisladamente problemas manifiestos.

Por último hay otro punto que considero el más importante, la conciencia de la gran mayoría, de la necesidad de un nuevo enfoque que permita analizar los problemas como manifestaciones interrelacionadas, para permitir un paso más fiel de ~~la~~ planeación a la ejecución. El análisis de toda la problemática del desarrollo y de sus intentos de solución desde el marco conceptual de la ciencia de los sistemas,como enfoque que permite a un grupo multidiciplinario el comprender un proceso dinámico y participar con pleno conocimiento en la toma de decisiones.

En esta primera parte vamos a ver someramente que son los sistemas y como influyen en el proceso de planeación. Vamos a seguir en principio algunas ideas que, aunque del dominio público, George Chadwick en su libro "A Systems View of Planning" nos proporciona en cierta secuencia que se acomoda a nuestra introducción, es quizá también el principio de todo tratado sobre sistemas.

Después de millones de años de existir este planeta, surge de un pasado impreciso, una especie que empieza a diferenciarse de otras en sus facultades de juicio y selección hasta llegar a establecerse y a hacer uso y modificaciones a los recursos a su alrededor.

Analicemos su medio ambiente. Hay nueve planetas en el sistema solar que conocemos y aunque esto es sólo una pequeñísima parte del sistema galáctico que empezamos a descubrir, en él está la Tierra, uno de los más pequeños planetas de este sistema solar. Esta está envuelta de una delgada capa que pesa quizá una milmillonésima parte del peso total del planeta, un fenómeno quizá trivial en términos cósmicos, pero esta delgada capa de seres vivos es para nosotros la circunstancia principal de nuestra existencia. El hombre no es más que uno de los tantos integrantes de esa capa, uno de los más recientes. Y a pesar de tener más poder que cualquier otro ser sobre el planeta, sigue siendo tan solo una parte de la película que nos envuelve. Como los demás seres necesita aire para respirar y le es indispensable el agua. En su movilidad está estrechamente adherido a la tierra; a pesar de su inteligencia el hombre está perdido sin lo que produce la tierra como alimento y para manufactura; no podría sobrevivir sin vegetación, sin los productos de distintas capas geológicas, sin lluvia, sin sol, viento, todo lo que forma su cambiante y en cierto sentido estático medio ambiente, El mismo de otras especies y plantas. El hombre es parte de la ecología del planeta, un sistema de interrelaciones entre la tierra, su atmósfera, su clima, su vegetación y sus habitantes de una admirable complejidad y que es aún una diaria experiencia humana.

Aunque complejas, ya estamos acostumbrados a agrupar estas interrelaciones cuando describimos alguna situación, por ejemplo, hablamos del sistema cósmico para describir aquellos fenómenos que están en el extremo de lo mayor que podemos imaginar y de sistemas de átomos, cuando queremos describir lo más pequeño que podemos concebir.

Asimismo, describimos relaciones entre grupos de animales localizados en su medio ambiente, con su vegetación y su clima como un sistema ecológico o ecosistema, con variaciones en tamaño y complejidad entre sus relaciones en los que podemos tener conjuntos y subconjuntos de acuerdo a patrones de comportamiento, alimentación, especie, sexo, etc. Estos conjuntos y subconjuntos son los sistemas y subsistemas de nuestro ecosistema o sistema ecológico total.

El hombre como ya mencionamos, es solo una especie animal en el mundo, pero es un animal diferente que compite en muchos campos con otras especies para invariablemente resultar el vencedor.

Como otros animales el hombre se encuentra ante la necesidad de ajustarse a las condiciones naturales, pero a diferencia de los demás es capaz también de modificar éstas hasta cierto grado. Tanto el hombre como los animales necesitan comida. Esto era y es proporcionado aniquilando otras especies y consumiendo plantas, pero los animales a diferencia del hombre buscan aquello que está disponible naturalmente y el hombre modifica las circunstancias para poder cultivar ciertas plantas que le sirvan de alimento a él ó a los animales que ha domesticado. Aquí el hombre agricultor ha modificado los sistemas naturales para satisfacer sus necesidades.

Estudiando los sistemas naturales vemos que el hombre ha contribuído a producir sistemas modificados o subsistemas dentro del contexto de los ecosistemas naturales. El hombre se ha movido de buscar refugios naturales como árboles y cuevas a construír su propia vivienda, primero de materiales naturales que aparentemente le imponían limitaciones fijas (como el tamaño de las rocas o el largo de los troncos) hasta llegar a lo de ahora, un refugio de materiales sintéticos con clima artificial. Hemos modificado las condiciones naturales con la idea de proporcionarnos un mejor alojamiento y por mayor tiempo del que lograría la naturaleza por sí misma. Aquí podemos ver que el hombre aparece como una especie "optimizadora" (valga la expresión) en bases distintas a los demás.

Ellos optimizan ajustándose con sus limitaciones a las condiciones naturales o evolucionando en seres mejor adaptados a esas condiciones. El hombre es un ser ya evolucionado que es capaz tanto de adaptarse a las condiciones naturales como a buscar concientemente cómo optimizar sus recursos y modificar a su gusto el sistema natural existente.

En esta búsqueda de lo óptimo el hombre estimará una situación futura como base con la cual comparar las posibles soluciones a un problema presente, es decir, él se decidirá por aquella alternativa que considera lo llevará a la situación deseada por la línea del menor esfuerzo. El hombre intenta minimizar sus recursos hacia un objetivo establecido o de maximizar sus resultados a cambio de un recurso dado.

Estas consideraciones han sido un intento de mostrar al hombre en su relación con el mundo en que vive; se ha hecho quizá a expensas de otros aspectos que son por lo menos igual de importantes, pero un paso necesario ya que nos ha dado un concepto muy general de lo que son los sistemas y la planeación.

GRAFICA 1

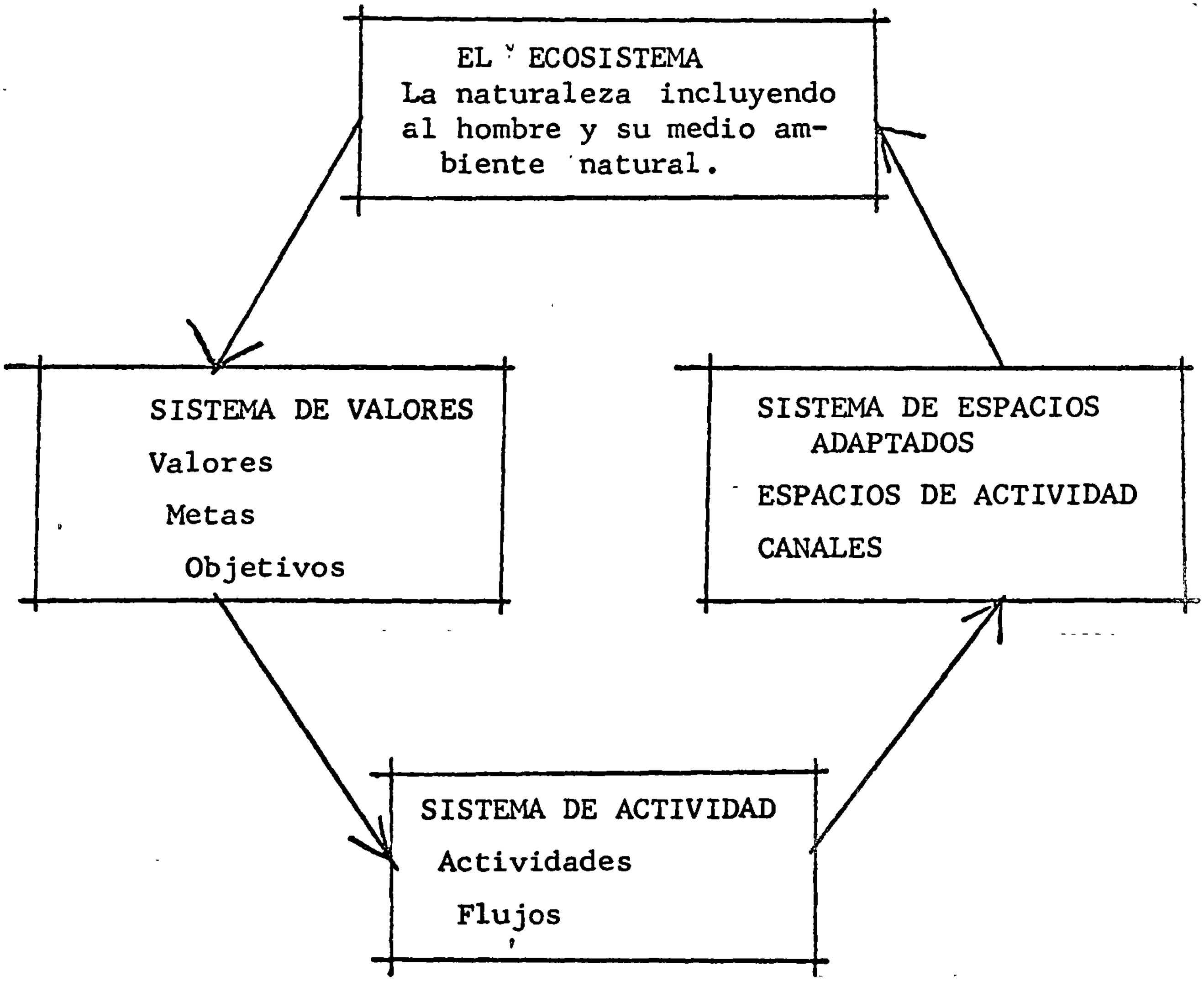
Esta gráfica intenta mostrarnos algo de básica importancia. El sistema de valores humanos es la habilidad de raciocinio que nos guía a valuar unas cosas más que otras, y el adjudicarle éstos valores a diferentes situaciones es lo que motiva al hombre a hacer todo lo que hace. El sopesar éstos valores conduce a formular ciertos ideales, a establecer las metas por alcanzar y los objetivos de su conducta diaria, por consecuencia a planear.

El tener valores, de cualquier tipo, es lo que motiva al hombre a actuar ya sea escalando una montaña, casándose o yendo a Oaxaca a descansar.

PAUSA

Todas estas actividades tienen una localización; algunas ocurren en áreas geográficamente determinadas que podríamos llamar "espacios de actividad" y otras ocurren cuando éstos espacios fluyen o se interrelacionan y surgen "conductos o canales de actividad". Tanto los espacios y sus flujos son considerados como parte de un mismo sistema de actividad y ambos ocupan un espacio físico y pueden ser representados o codificados en un sin número de formas de acuerdo a las necesidades de cada estudio en particular.

Aunque tenemos conjuntos de relaciones complejas empezando por el hombre y su lugar en la naturaleza, por los valores que este hombre sustenta, por su conducta y finalmente por su intento de modificar la naturaleza. Podemos considerar que de este simple diagrama se desprenden todas las consideraciones que a mayor profundidad podamos realizar.



EL SISTEMA HOMBRE - NATURALEZA

SISTEMAS.

DEFINICIONES DE SISTEMA.

Diccionarios.

1) Conjunto de reglas o principios enlazados entre sí.

2) Conjunto de cosas que ordenadamente relacionadas entre sí, contribuyen a determinado objeto.

3) Biol. "Conjunto de órganos que intervienen en alguna de las principales funciones vegetativas".

Johnson.

Un sistema es un todo organizado y complejo, implica un complejo interconectado de componentes o partes fundamentalmente relacionadas, que forman un todo unitario.

Chorofas.

Combinación o disposición ordenada de diversas partes o elementos en un todo indivisible.

Las partes o elementos que forman tal sistema deben considerarse como integradas y no simplemente agregadas.

Gibson.

Un sistema es un conjunto integrado de elementos interactuantes diseñado para llevar a cabo en forma cooperativa una función predeterminada.

Buckley.

Sistema es un complejo de elementos o componentes directa o indirectamente <u>relacionados</u> en una red <u>causal</u>, de modo que cada componente está relacionado de modo más o menos estable, en un lapso dado.

Moray.

Un sistema es todo conjunto de atributos y la historia de los cambios que ocurren en ese conjunto.

Von Bertanlanffy.

Un sistema es un conjunto de elementos en interacción. Hay leyes generales para los sistemas independientes a la naturaleza de los elementos componentes y de las relaciones entre ellos.

Wilson & Wilson.

Un sistema es un conjunto de partes interdependientes o interactuantes, cuyas relaciones entre sí o entre sus atributos, determinan un todo unitario que realiza determinado efecto, función u objetivo.

Hall.

Un sistema es una serie de objetos con determinada relación entre ellos y sus propiedades.

SISTEMA.

- Conjunto o combinación de objetos o partes;
- Integradas e interdependientes
- Cuyas relaciones entre sí y con sus propiedades las hacen formar un todo unitario y organizado;
- Que cumple determinado propósito o realiza determinada función,
- Y que puede mantener cierto grado de estabilidad, aunque la materia y la energía que lo compongan estén sujetos a cambios constantes.

TEORIA GENERAL DE LOS SISTEMAS.

Boulding.
Von Bertanlanffy
Shoderbeck
Hopkins.

Es el esqueleto científico que provee el marco de referencia o la estructura por la cual las diversas disciplinas pueden ser orientadas, integradas y hacerse mutuamente provechosas.

Su campo es el de la lógica-matemática, entre las altamente abstractas generalizaciones de las matemáticas y el nivel de generalización de las disciplinas específicas.

Para lograr esos objetivos una teoría general de los sistemas deberá partir de una serie de postulados que describan el comportamiento de cualquier sistema y permita predecir su comportamiento futuro.

Por lo que Duhalt Krauss propone los siguientes:

AXIOMAS O POSTULADOS BASICOS.

1.- Integración.- Un sistema es un todo indisoluble que está integrado por partes interrelacionadas, interactuantes e interdependientes de tal manera que ninguna parte puede ser afectada sin afectar a las otras partes.

2.- Subordinación.- El todo es primario y las partes secundarias. El papel que juegan las partes depende del propósito para el cual existe el todo.

3.- Dependencia.- La naturaleza de la parte y su función, se derivan de su posición dentro del todo y su conducta es regulada por la relación del todo a la parte.

4.- Unidad.- El todo se conduce como una unidad, no importando su grado de complejidad.

5.- Estabilidad.- La identidad del todo y su unidad se preservan aunque las partes cambien. El todo se renueva a sí mismo constantemente a través de un proceso de transposición.

6.- Organización.- El todo es más que la suma de las partes. El todo tendrá características diferentes que la de los componentes en forma individual.

7.- Jerarquía.- Los sistemas están relacionados en forma jerárquica. Las partes de un sistema pueden ellas mismas ser sistemas (subsistemas de un sistema mayor) y las partes de éste, pueden ser a su vez, sistemas.

EL ENFOQUE SISTEMICO.

Enfoque sistémico es aquel que concibe cualquier fenómeno como un sistema; parte de un sistema o como un conjunto de sistemas.

CLASIFICACION DE LOS SISTEMAS.

Se han elaborado varias clasificaciones de los sistemas dentro de diversos campos pero quizá una de las más sencillas y útiles sea la de Stafford Beer que se basa en los principios de probabilidad y determinismo.

- SISTEMAS DETERMINISTICOS SIMPLES
- SISTEMAS DETERMINISTICOS COMPLEJOS
- SISTEMAS PROBABILISTICOS SIMPLES
- SISTEMAS PROBABILISTICOS COMPLEJOS

Una computadora electrónica, por ejemplo, es compleja pero determinista, ya que solo ejecuta aquellas operaciones para las cuales ha sido programada.

Por otro lado, el lanzar una moneda al aire podrá parecer un sistema simple, y lo es ya que solo hay dos resultados posibles; pero es probabilístico ya que es impredecible ese resultado.

NIVEL DE RESOLUCION EN LOS SISTEMAS.

Debido a la posibilidad de definir un sistema de un número ilimitado de formas, de acuerdo a nuestro propósito e interés; debemos una vez establecido éste, en términos de elementos, atributos e interrelaciones, el hacer un análisis riguroso de cual va a ser nuestro nivel de apreciación y determinación del sistema.

Klir y Valack han denominado a esto el "NIVEL DE RESOLUCION" de un sistema.

"En un nivel de resolución 'alto' una mesa es un sistema de moléculas, de muchos elementos con una serie de interrelaciones complejas entre ellos.

A un nivel de resolución 'medio' la mesa es un sistema estructural de varios elementos: patas, cubierta y cargas sobrepuestas.

A un nivel de resolución más bajo la mesa pierde su significado individual, convirtiéndose en un incidente de un sistema perceptual o en una pequeña carga de una estructura mayor".

Un nivel de resolución de éstos, debe ser el importante para nosotros, los otros no los debemos considerar ya que no intervienen en nuestro objetivo final.

Este es un principio que debemos tener siempre presente al aplicar el enfoque sistémico a cualquier campo.

ESCALA DE UN SISTEMA.

- Medio ambiente
- Sistema
- Subsistemas
- Elementos o componentes

- MEDIO AMBIENTE DEL SISTEMA.- El conjunto de todos los sistemas que no son el que estamos considerando.

Nunca estamos interesados en los sistemas del medio ambiente, pues de estarlo los habríamos incluído en nuestro sistema definido.

- SISTEMA.- El conjunto total definido a cierto nivel de resolución.
- SUBSISTEMAS DEL SISTEMA.- Partes del sistema que tienen -- cierta intercomunicación que los diferencía de otras partes del todo, pero que siguen claramente perteneciendo a él.
- ELEMENTOS O COMPONENTES DEL SISTEMA.- Las partes más pequeñas del sistema, el límite más bajo de análisis y detalle; nos interesa su comportamiento más no su estructura. Los elementos de un sistema son "cajas ciegas" de cuya estructura no sabemos nada excepto lo que podemos deducir de su comportamiento, de sus características de insumo y producto.

Una caja-ciega se considera como un proceso contenido dentro de ciertos límites, del cual sólo nos interesa lo que entra como insumo y lo que sale como producto.

Estas relaciones insumo-producto son las que manejaremos en el sistema del cual forman parte esos elementos.

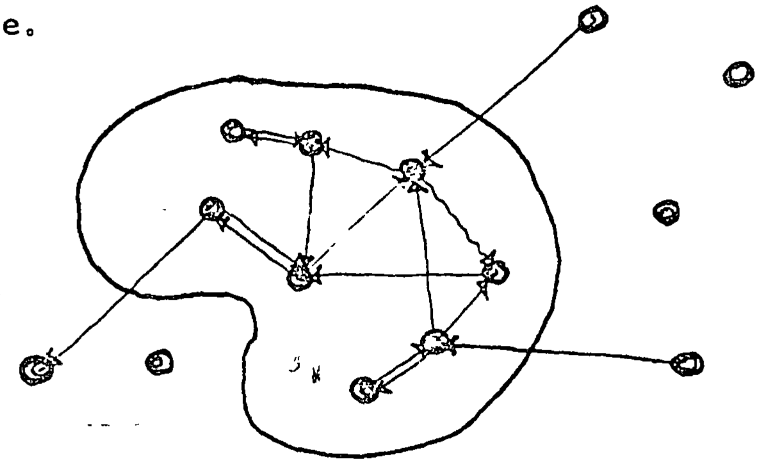
El concepto de "caja ciega" es muy útil en la planeación y muchos sistemas y subsistemas se pueden tratar así al querer subir el nivel de resolución.

EJEMPLO: Un partido de fútbol o un edificio en la planeación urbana

Medio ambiente = el público
Sistema = el juego
Subsistemas = cada equipo
Elementos = cada jugador

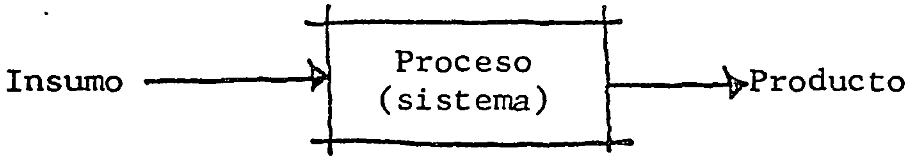
REPRESENTACION DE UN SISTEMA.

Gráficamente.



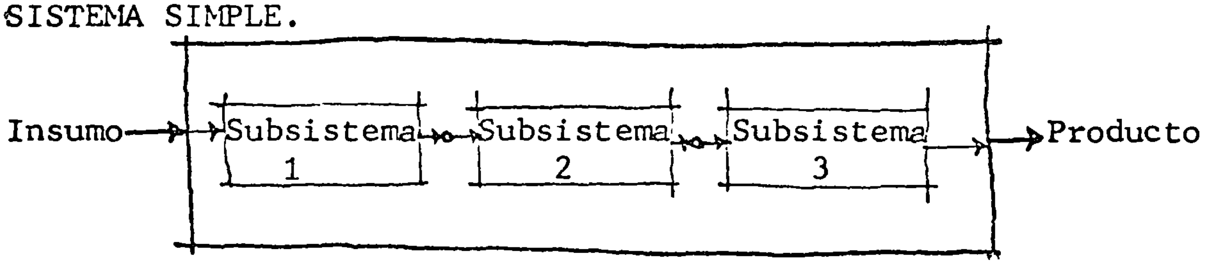
Los círculos representan un conjunto de elementos que pueden considerarse "cajas ciegas". Algunos elementos fuera del límite del sistema son escogidos debido a la importancia de sus relaciones. Las flechas que cruzan el límite son insumos o productos del sistema.

"CAJA CIEGA"

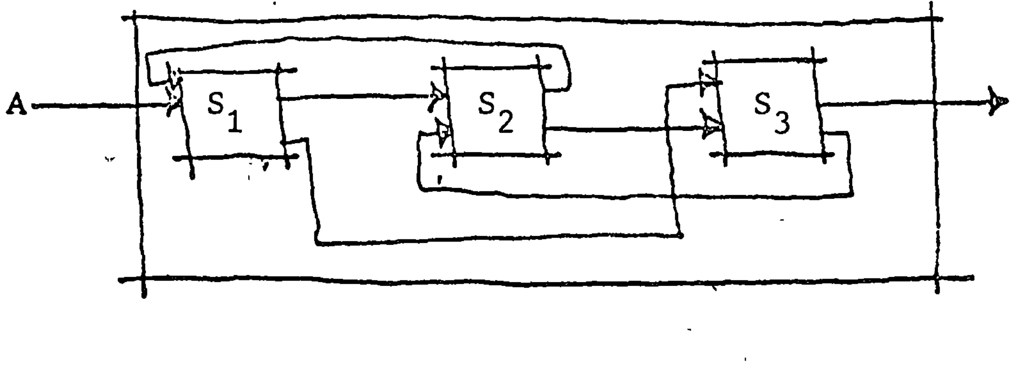


Flujo de información, energía o materia

SISTEMA SIMPLE.



SISTEMA CON RETROALIMENTACION



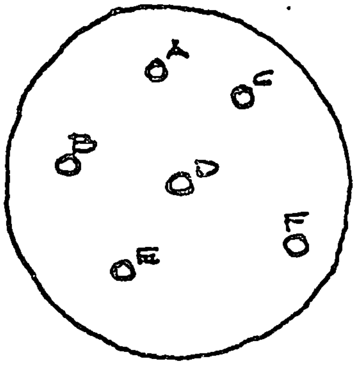
TAMAÑO DE UN SISTEMA.

Al determinar el nivel de resolución de un sistema estamos estableciendo el tamaño de un sistema de acuerdo a nuestros objetivos.

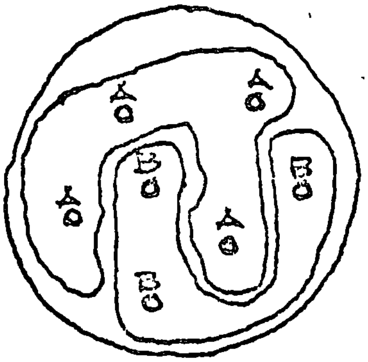
En los sistemas "tamaño" es más un concepto de complejidad que de medida física. El tamaño se determina por su "variedad".

Variedad es simplemente el número de estados que puede adoptar un sistema en relación al número identificable de elementos del mismo y a sus relaciones posibles.

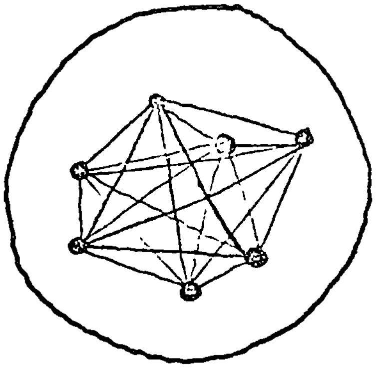
VARIEDAD



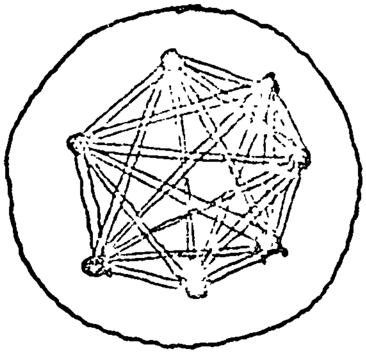
Elementos disímbolos sin interacción (no forman un conjunto)



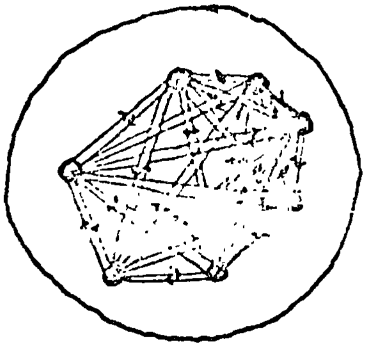
Grupo de elementos parcialmente similares (dos conjuntos)
dos estados = variedad 2.



Elementos disímbolos con interacción simple.
Sistema de 7 elementos con uniones simples.
Variedad = 21



Elementos disímbolos con doble interacción.
Sistema de 7 elementos con uniones dobles.
Variedad = 42



Sistema Dinámico: 7 elementos con uniones dobles.
Cada liga con interruptor on/off
Variedad = 2^{42} (Superior a 1 000.000'000,000)

REPRESENTACION DE UN SISTEMA.

Matemáticamente.

TEORIA DE LOS CONJUNTOS.

Sean $a_1, a_2, a_3, \ldots, a_n$; elementos contenidos en el sistema S.

Sea a_0: el medio ambiente del sistema.

Señalemos: el conjunto $A = (a_1, a_2, a_3, \ldots, a_n)$

el conjunto $B = (a_0, a_1, a_2, \ldots, a_n)$

por lo tanto B contiene todos los elementos de A más el elemento a_0 del medio ambiente.

Dejemos que todo elemento de B se caractèrice por un conjunto de elementos de entrada y un conjunto de elementos de salida.

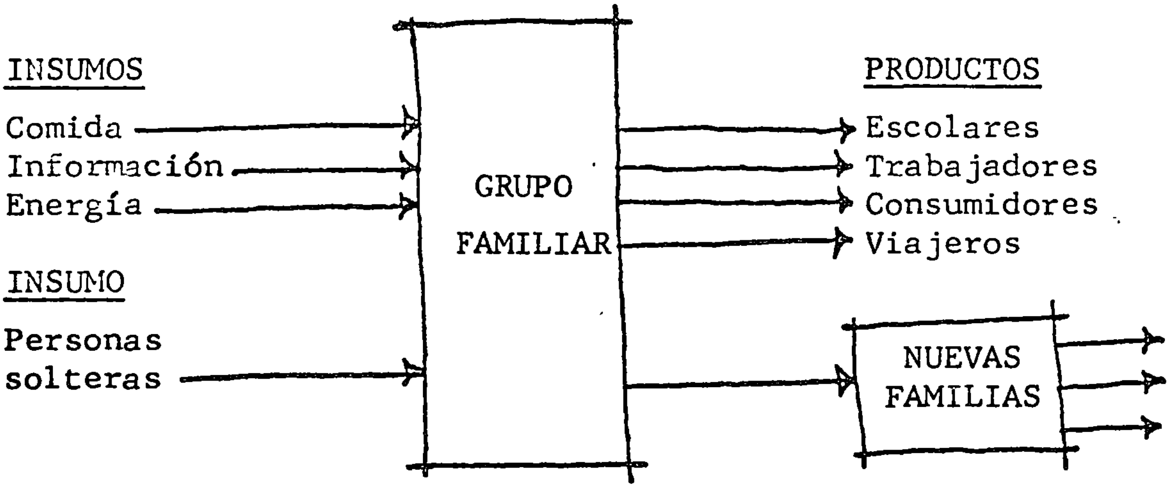
Sea r_{df} el modo en que las entradas del elemento a_f dependen de las salidas del elemento a_d, o sea el resultado de la relación entre estos elementos.

El conjunto de todos los r_{df} $(d, f, = 0, 1, 2, \ldots n)$ se representará por R.

Entonces podemos definir un sistema estableciendo que cada conjunto $S = (A, R)$ constituye un sistema.

EJEMPLOS SISTEMICOS.

El grupo familiar.



COMPONENTES del sistema de familia.- Personas. Actividades de personas, espacios adaptados para las actividades de personas.

INTERRELACIONES del sistema de familia.- Flujo de personas. Flujo de materiales (comida, agua, combustible, desechos,etc.) Flujo de energía. Flujo de información. Flujo de espacios - adaptados (vehículos).

DESCRIPCION DEL SISTEMA.- Probabilístico complejo, se requiere de muchos modelos para poderlo representar adecuadamente. (fertilidad, dinámica de población, demanda, empleo, movilidad) etc.

Manejo de los sistemas para su análisis y control.

ANALISIS DE SISTEMAS.

- INGENIERIA DE SISTEMAS.
- INVESTIGACION DE OPERACIONES.

CONTROL Y COMUNICACION DE LOS SISTEMAS.

- INFORMATICA
- ROCREMATICA

EL ANALISIS DE SISTEMAS.

Según su influencia con el resto del universo los sistemas pueden clasificarse en:

- Sistemas abiertos.- Aquellos que reciben influencia a través de vías específicas llamadas entradas y que ejercen influencia a través de vías específicas llamadas salidas.
- Sistemas cerrados.- Aquellos que no reciben ni ejercen influencia sobre el resto del universo.

Aunque los sistemas cerrados no existen este concepto es útil en el proceso de análisis de sistemas, ya que los sistemas abiertos son, por su naturaleza, generalmente demasiado complejos, aun para análisis simples.

Abriendo un sistema cerrado a nuevas variables ambientales externas y después cerrándolo, se puede observar y evaluar lo que pasa ante esas nuevas condiciones.

ANALISIS DE SISTEMAS.

INGENIERIA DE SISTEMAS.

Actitud mental y preparación cuantitativa del técnico que lo induce al análisis detallado de las componentes y relaciones del sistema en su medio ambiente.

- Establece las características que debe tener un sistema óptimo.
- Selecciona la combinación de subsistemas que formarán el sistema.
- Analiza las interacciones dentro del sistema.
- Establece las características de las partes para poder optimizar el todo.

Metodología empleada.

- Análisis Marginal.
- Análisis Beneficio-Costo
- Análisis Costo-Efectividad
- Análisis de Inversiones
- Análisis Operacional

Arthur D. Hall

ANALISIS DE SISTEMAS.

INVESTIGACION DE OPERACIONES.

La investigación de operaciones es una disciplina basada en técnicas y modelos matemáticos para la optimización de partes específicas o subsistemas una vez ya establecidas las limitaciones y relaciones con las demás partes y el todo.

Metodología.

- Formular el problema.
- Elaborar el modelo matemático que lo represente
- Obtener una solución del modelo
- Probar modelo y solución
- Retroalimentación
- Implantar la solución.

Churchman

Ackoff

Enthoven

Arnoff

Chadwick

EL CONTROL Y COMUNICACION DE LOS SISTEMAS.

LA CIBERNETICA.

La Cibernética es el estudio analítico del isomorfismo de las comunicaciones en los mecanismos (Ingeniería Cibernética) los organismos (Bio-cibernética y Psico-cibernética) y las sociedades (Socio-cibernética).

Los aspectos que estudia la Cibernética son los procesos de comunicación y control.

- Control de los sistemas de máquinas, de los procesos de producción y en general, de los procesos que tienen lugar cuando el hombre actúa con un fin determinado en los instrumentos de trabajo y en los procesos naturales.
- Control de la actividad organizada de las comunidades humanas que toman las decisiones.
- Control de los procesos que tienen lugar en los organismos vivos (fisiológicos, bioquímicos y biofísicos) superiores, relacionados con la actividad vital del organismo y encaminados a la conservación del mismo en las condiciones variables de su existencia.

CIBERNETICA.

Esto ha hecho que se desarrollen las ramas de la Cibernética:

- INFORMATICA.- Se ocupa de los sistemas de información, o sea, aquellos en los que el flujo es información.
- ROCREMATICA.- Se ocupa del flujo de material, abarcando las funciones básicas de producción, transporte, almacenamiento y distribución de productos.

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LA CIUDAD.

Una ciudad nace como un centro de intercambio económico, cultural, social, político, etc. etc. Es un gran "mercado" al cual concurren todos los elementos de una región, es decir, en un principio la ciudad no es más que una consecuencia de la región en su intento por organizarse.

En ella poco a poco empieza a surgir un nuevo hombre, el hombre urbano, el cual en un principio funciona solo como intermediario y en su desarrollo, pretende organizar y controlar a todo el medio ambiente productor. Este nuevo hombre, intenta solamente optimizar y sacar provecho de los factores que concurren en cada ciudad. Así llega la industrialización, en donde el hombre urbano empieza a sistematizar y capitalizar la producción de bienes de consumo y capital. Es aquí cuando el hombre urbano empieza a desarrollarse independientemente del medio regional del que dependía, empieza a crecer su influencia y a interrelacionarse con otras regiones y ciudades. El campo pierde fuerza y empieza a convertirse solamente en un proveedor de materia prima a cambio de consumir unos cuantos productos urbanos.

Como la ciudad maneja los patrones de consumo y es la que más fácilmente puede organizar y establecer precios, empieza a explotar al campo no pagándole en proporción a su aportación de productos. El campesino al ver ésto cree que la ciudad ha hecho un milagro económico y emigra a ella tratando de incorporarse a la clase dominante.

El Gobierno como producto generalmente urbano se dedica a intentar optimizar el sistema también urbano olvidándose de sus ligas e interrelaciones con la región.

Esto es posible en países donde la mayor parte de la población es urbana (USA, GB) y donde se ha integrado al campo dentro de un proceso de industrialización, pero injusto y explosivo en países donde el 50% de la población es rural.

El problema además no es querer optimizar el sistema urbano, sino el pretender hacerlo simplemente cubriendo aspectos aislados (vivienda popular, vialidad, educación, contaminación, etc. etc.) sin estar concientes de las relaciones que tienen todos los elementos entre sí, para así poder preveer y optimizar el impacto de cada inversión.

La ciudad no es más que una serie de actividades representadas por los edificios y una serie de ligas e interrelaciones entre ellos, esto aunque fácil de decir es terriblemente complejo en su funcionamiento y en su organización..

El edificio como parte de este sistema urbano, no pretende más que optimizar su accesibilidad a toda esta serie de canales de interrelación; como consecuencia al planear un edificio debemos preveer y planear sus ligas con otras actividades y con el medio ambiente, ya que de esto dependerá su buen funcionamiento dentro de la comunidad.

A continuación se presenta un estudio realizado en la Comisión del Desarrollo Urbano del País de la Secretaría de Obras Públicas en un intento por estudiar y sistematizar el análisis de la influencia y repercusión de cualquier establecimiento en un medio urbano, dentro del marco general de desarrollo de un proyecto.

Como primer paso en el desarrollo del proyecto, consideramos necesario el establecer un marco de referencia de todas las actividades por realizar, así como de las responsabilidades que cada uno de los integrantes del equipo tendrá ante el problema. Con este propósito se elabora un MODELO CONCEPTUAL como esquema teórico de referencia de cada actividad.

Dicho modelo consta básicamente de los siguientes elementos:

- DEFINICION DEL PROBLEMA En el cual se establece claramente el problema, basado en estudios sobre ese tema y en los puntos analizados en las juntas de coordinación celebradas con los interesados en el proyecto y con el promotor.

- ESQUEMAS TEORICOS cuyo propósito es el de representar gráficamente todos los pasos y procesos metodológicos empleados en las distintas etapas del proyecto.

- TABLA DE TEMAS en la cual se establecen claramente cuales son las metas del proyecto, así como los objetivos que se habrán de cumplir para lograr dichas metas, objetivos concretos derivados del conocimiento del lugar y de las metas, que nos servirán como una medida de efectividad en el modelo de evaluación.

- INVESTIGACION; dividida en los siguientes sub-temas:

  - INVESTIGACION FISICA, elaborada por medio de las encuestas hechas por los becarios.
  - INVESTIGACION SOCIO ECONOMICA, recopilando por un lado, la información necesaria de la zona de influencia; población, actividades existentes, inversiones en infraestructura y estructura dentro de la zona y el marco jurídico institucional existente; por otro lado se deberá determinar que estudios a partir de esta información nos son de utilidad; las posibilidades físicas de cambio, las hipótesis de crecimiento demográfico, el papel de nuestra instalación en el desarrollo de la zona, el papel de la zona en el desarrollo de la ciudad, la población y recursos disponibles y requeridos, la jerarquización de las actividades económicas, las alternativas de distribución de población y actividades, la evaluación y estimación de las inversiones requeridas, las alternativas de financiamiento y por último, el marco jurídico institucional necesario para poder implementar el proyecto.
  - INVESTIGACION BIBLIOGRAFICA, analizando información existente sobre estudios similares.

- INVESTIGACION FINANCIERA, la cual estudia los recursos necesarios y disponibles, así como la factibilidad del proyecto.

- SUB-MODELO DE ACTIVIDADES E INTERRELACIONES el cual consiste en analizar cuales son las actividades que concurren en el medio urbano, sus interrelaciones, su importancia, su frecuencia de uso y en general, todos los datos necesarios para integrar un programa completo y los modelos de evaluación del funcionamiento de cada una de las alternativas que posteriormente se presenten.

- PLANES PILOTO, que van tratando problemas específicos y proponiendo soluciones que más adelante se podrán manejar en la elaboración de alternativas de proyecto.

- PLAN PRELIMINAR, etapa donde concurren y se integran los trabajos y estudios anteriores; clasificando y conciliando la información, así como evaluándola para poder desarrollar un programa detallado que analice sus efectos hacia la zona y hacia la ciudad.

- PROGRAMA, que consiste en una relación pormenorizada de las actividades que se llevarán a cabo en la zona, las áreas necesarias para éstas y los criterios generales de localización einterrelación, expresado por medio de coeficientes, normas, rangos y patrones de diseño.

- POBLACION Y ACTIVIDADES DESEADAS Y DISPONIBLES, producto directo del programa, donde se mencionan aquellas actividades y población necesarias al proyecto, así como aquellas actividades y población que habrá disponible para acomodar en otros programas.

- MODELO DE EVALUACION, este modelo analizará tres aspectos de cada alternativa que se genere:

  - ASPECTO FORMAL, en el cual se evaluará de acuerdo a los objetivos concretos derivados de la tabla de metas en cuanto a adecuación de la alternativa al problema, su integración al medio ambiente, sus posibilidades de ejecución, carácter, su flexibilidad, su posibilidad de adaptación a distintas etapas de realización, la optimización en el uso de las inversiones existentes de infraestructura y en su relación con los demás objetivos.

- ASPECTO FUNCIONAL; a partir del programa se elaborará un modelo óptimo de funcionamiento y cada alternativa se evaluará comparando su funcionamiento con ese modelo óptimo, aplicando factores de restricción a cada interrelación que no cumpla con el rango permitido .
- ASPECTO ECONOMICO; cuantificando todos los costos así como los beneficios esperados de cada alternativa, para poder hacer una evaluación de tipo costo-beneficio con una tasa de rentabilidad fijada previamente por el estudio financiero.

- ELABORACION DE ALTERNATIVAS; las cuales deberán contener un criterio formal completo, un modelo de funcionamiento, su costo, así como los beneficios esperados; para poderlas evaluar.

- SELECCION DE UNA ALTERNATIVA Y DESARROLLO DEL PROYECTO.

- PROGRAMACION E IMPLEMENTACION DEL PROYECTO.

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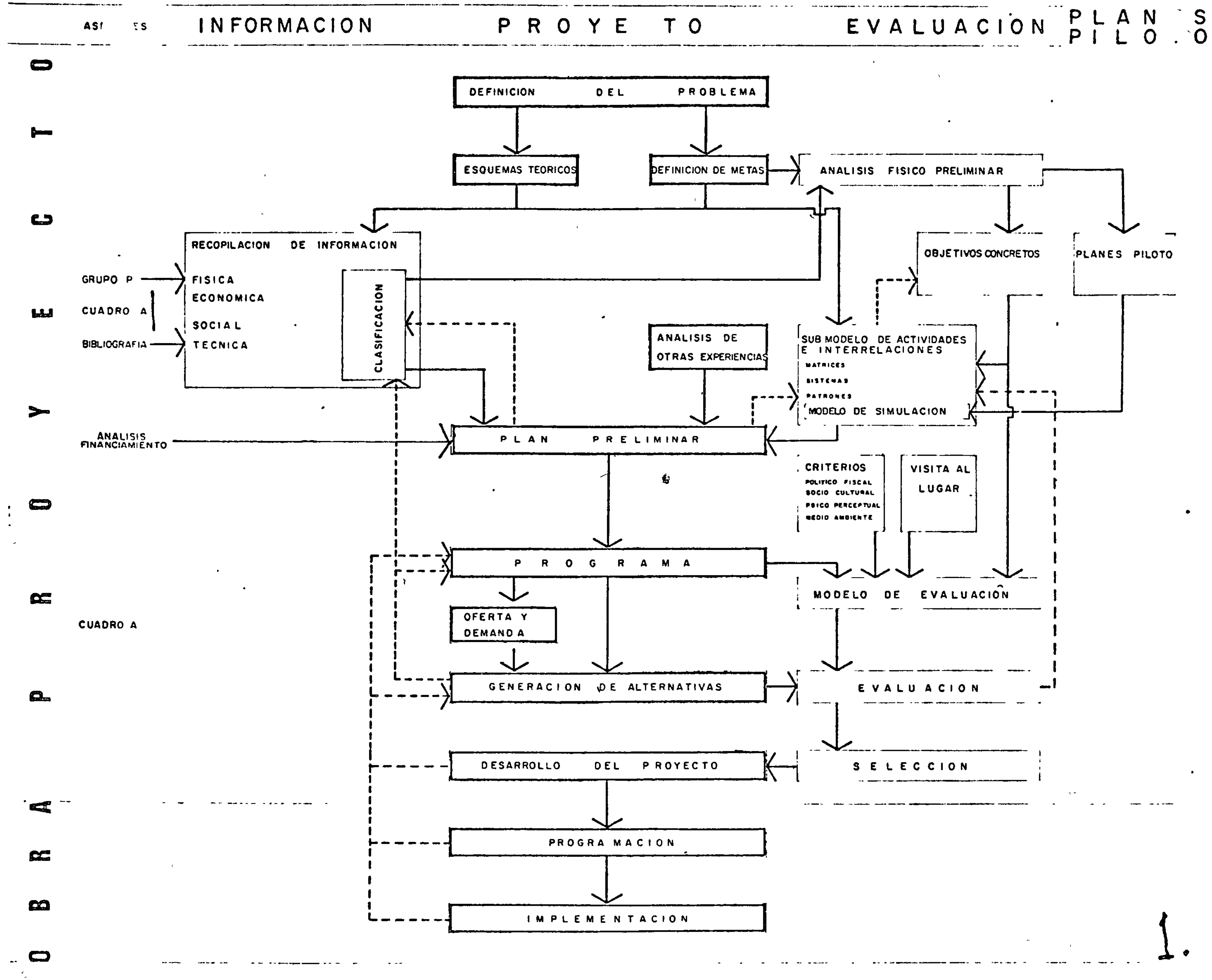
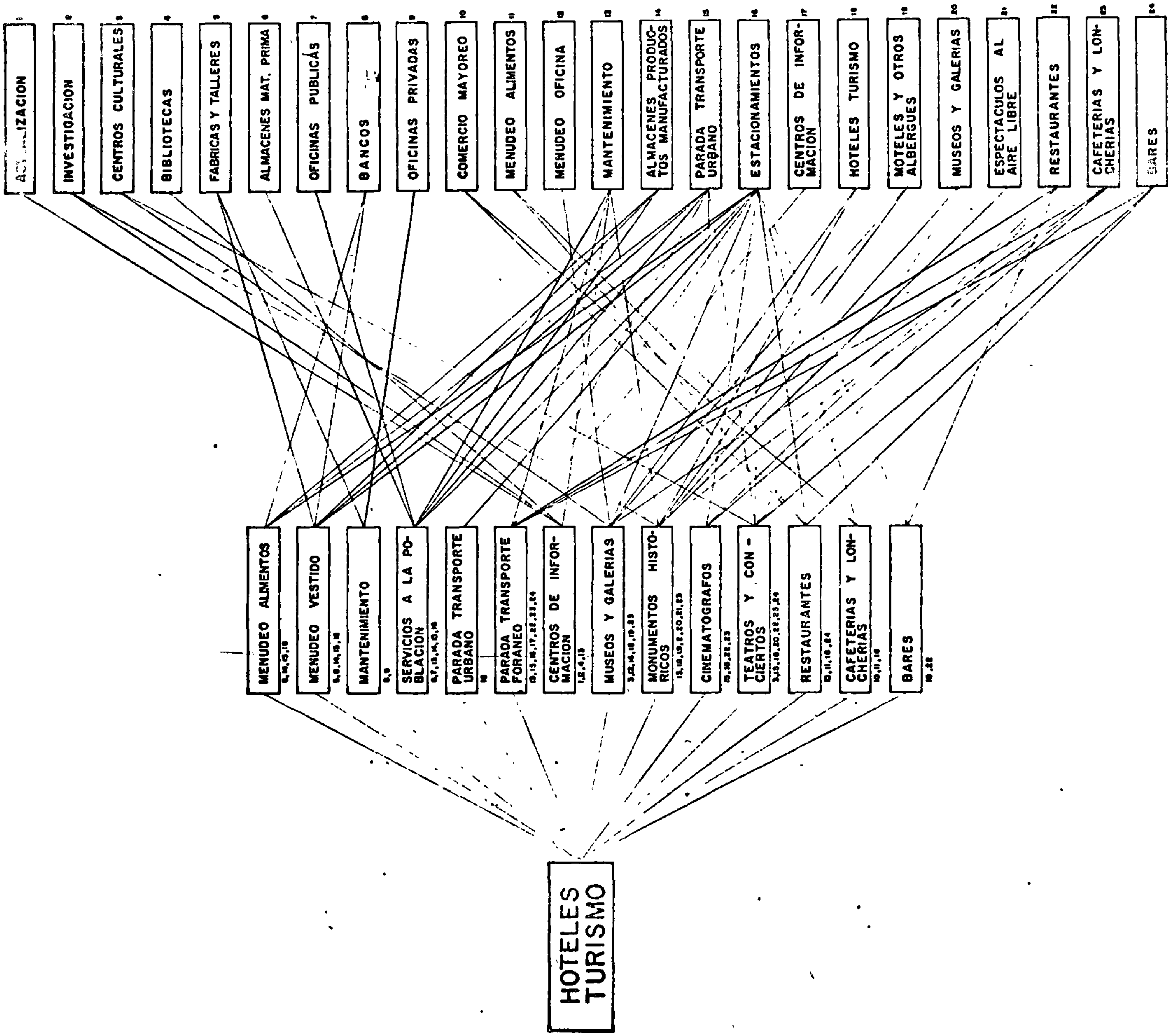
MODELO CONCEPTUAL



1.

SEMIRRETICULA DE RELACIONES



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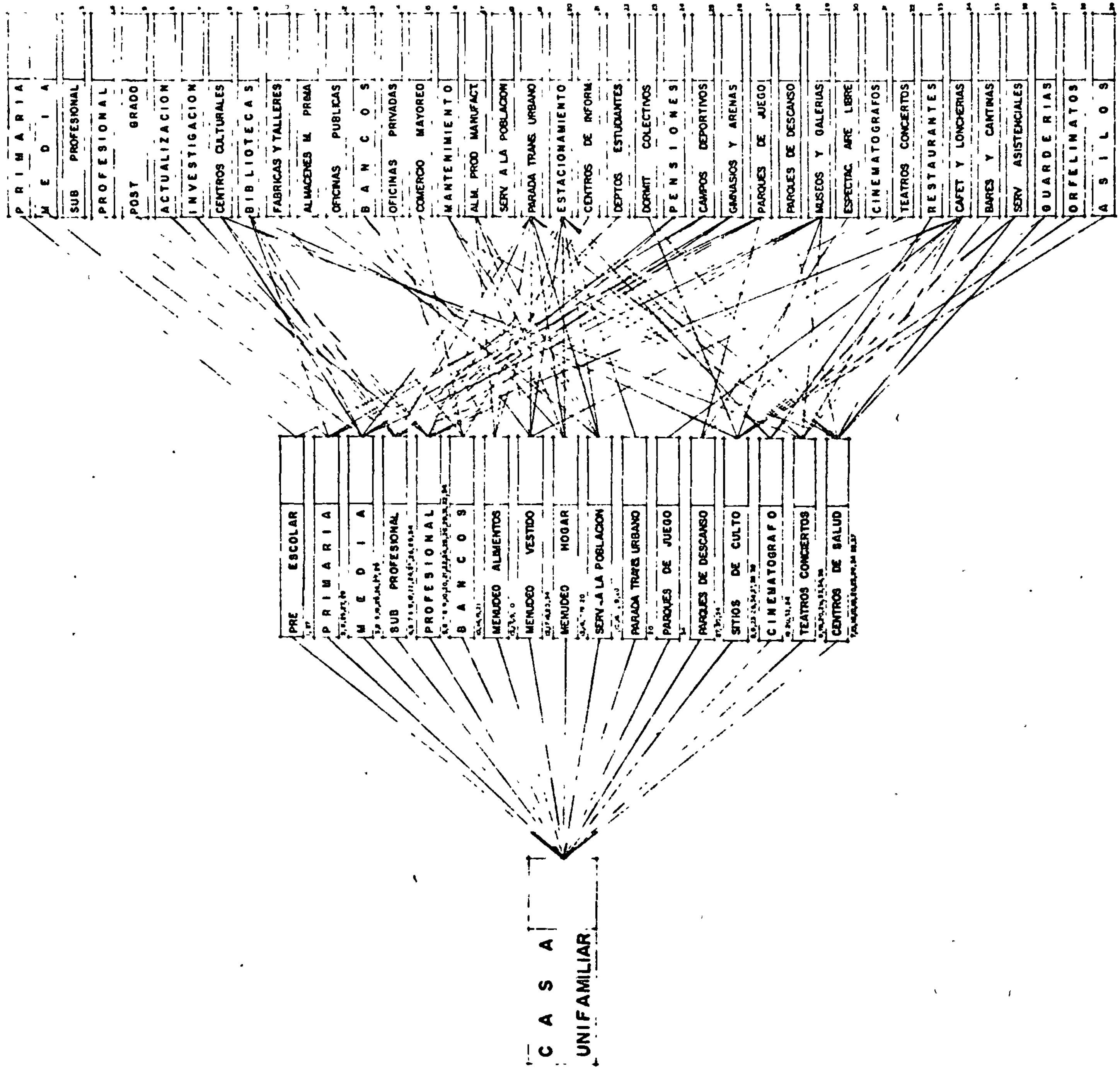

centro de educación continua
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ANALISIS ECONOMICO Y PLANEACION DE EDIFICIOS

EL MEDIO AMBIENTE NATURAL

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1. EL MEDIO AMBIENTE NATURAL.

Las características físicas, culturales y estéticas del sitio en que va a operar o ser usado un sistema, influyen decisivamente en sus requisitos o especificaciones de proyecto. El análisis del sitio o medio ambiente tienen como objetivo adecuar el sistema a las características naturales del sitio.

En general los problemas que plantea el medio ambiente por estudiar son las características del sitio en que se establecerá el edificio o sistema, definiendo las restricciones que este impone al problema.

Este análisis puede iniciarse a un nivel de mayor generalidad cuando aún no se ha determinado el sitio exacto de ubicación del sistema, contando solo con su macroubicación en una región o ciudad. Tal macroanálisis permite realizar una selección de los sitios disponibles, escogiendo el que mejor satisface las especificaciones referentes al sitio.

Una vez realizada esta selección se puede proceder a realizar el microanálisisdel terreno escogido; para determinar las restricciones que impone el terreno escogido.

Procede entonces a realizar la selección del sitio, en base a los requerimientos o especificaciones del programa, escogiendo aquel que mejor satisfaga las experiencias en el expresadas. No siempre existe la posibilidad o necesidad de realizar una selección: en aquellas situaciones en que el sitio está ya predeterminado. En cualquiera de ambos casos se procede entonces al análisis del sitio.

Como ya se ha mencionado nuestro objetivo es adecuar el sistema a las restricciones naturales que nos impone el sitio.

Generalizando las restricciones mayores que nos presentan el medio ambiente natural influyen directamente en el sistema morfológico del edificio.

La reglamentación para dichas condiciones se agrupan en normas que llega de lo particular a lo general; pudiendo nosotros enunciar las normas generales en los partidos estructurales.

2 PARTIDOS ESTRUCTURALES.

2.1 ESPACIAMIENTO Y LOCALIZACION DE COLUMNAS:

En edificios mayores de cuatro pisos, se recomienda tener uniformidad en los claros adyadcentes para tener elementos tipo hasta donde el sistema funcional lo permita.

2.2 LOCALIZACION DE ELEMENTOS DE RIGIDEZ DEPENDIENDO DE LA FORMA DE LOS EDIFICIOS EN PLANTA.

Procurar tener la mayor simetría de elementos rígidos.

2.3 LA FACHADA COMO ELEMENTO ESTRUCTURAL.

Aprovecharlas siempre y cuando no produscan excentricidades importantes en el edificio.

2.4 RELACION DE ESBELTEZ.

Es aconsejable que la relación de altura o ancho no sea mayor de 6.

2.5 SISTEMAS DE PISO.

2.5.1 TRABES Y LOSAS COLADAS MONOLITICAMENTE INSITU.

Es recomendable emplearlo hasta 8.00 M de claro con cargas vivas hasta 500 Kg/M2 . De preferencia el peralte debe variar entre 1/10 y 1/12 del claro libre entre apoyos.

Para cargas mayores es aconsejable trabes con un peralte igual a 1/8 a 1/10 del claro.

2.5.2 LOSAS PLANAS CON ELEMENTOS PARA ALIGERAR.

De 8.00 a 12.00 es recomendable el uso de este sistema. Sobre todo cuando se tiene limitaciones de altura.

2.5.3 ELEMENTOS PRECOLADOS Y PRESFORZADOS DE CONCRETO.

Se recomienda su empleo para claros mayores de 12 M. en estructuras hasta de tres niveles con uniformidad de claros en planta.

2.5.4 ELEMENTOS DE CONCRETO POSTENSADOS COLADOS INSITU.

Es recomendable emplerse cuando se tiene limitaciones en el peralte del sistema de piso y se desea dejar la estructura aparente, para claros mayores de 12M. y cargas vivas mayores de 250 Kg/M2

2.5.5 TRABES METALICAS CON LOSA PRECOLADA O COLADA IN SITU.

Es recomendable para claros mayores de 10 M. y para edificios altos localizados en zona de alta compresibilidad.

2.6 JUNTAS CONSTRUCTIVAS.

2.6.1 ESPACIAMIENTO DE JUNTAS DE DILATACION DEPENDIENDO DE LA LONGITUD DEL EDIFICIO.

Generalmente no es necesario tener juntas de dilatación - en edificios de 60 a 80 M. pero es recomendable tener una junta sobre todos en terrenos de alta compresibilidad.

2.6.2 JUNTAS DE DILATACION DEPENDIENDO DE LA FORMA EN PLANTA DE LOS EDIFICIOS.

Es aconsejable buscar la simetría del edificio con juntas de dilatación.

2.7 MUROS COMO ELEMENTOS ESTRUCTURALES.

2.7.1 DE CONCRETO

Es recomendable su empleo en edificios altos de 10,15 o - 20 pisos, buscando siempre que dichos muros tengan la mayor inercia.

2.7.2 DE TABIQUE.

Pueden ser de rigidez o de carga, se pueden emplear en edificios hasta de 8 pisos debiendo de preferncia estar localizados uniformemente en planta . Debiendo estar siempre confinados.

4 Pisos carga viva normal	e= 14 cm.
4 a 8 Pisos Carga viva normal	e= 28 cm. y e= 14cm.

2,8 COLUMNAS.

2.8.1 De conreto armado cuando es necesario limitar su sección transversal utilizando concretos de alta resistencia y utilizando porcentajes de 4 a 5 por ciento de acero de refuerzo.

2.8.2 De acero donde se requiere limitar demasiado la sección -- transversal y en conjunto con el sistema de piso.

3 TIPOS DE SOLICITACIONES:

Suelen clasificarse como sigue las solicitaciones que o-- bran en las estructuras.

3.1 FUERZAS IMPUESTAS AL SISTEMA;

3.1.1 FUERZAS GRAVITACIONALES.

a).- Cargas muertas Reg. Const. D. D. F. (CAP. XXII)

b).- Peso y empuje de Líquidos y matriales granulares -- almacenados.

c).- Cargas vivas Reg. Const. D. B.F. (CAP. XXIV)

3.1.2 FUERZAS ACCIDENTALES.

a).- Fuerzas de inercia debidas a sismo y fuerzas provenientes de deformaciones impuestas por sismo.

b).- Presiones de viento y fuerzas de inercia provenientes de vibraciones causadas por la variación de estas previsiones.

c).- Vibraciones debidas a maquinaria y otras solicitaciones dinámicas debidas al funcionamiento de Equipo Mecánico.

3.1.3 DEFORMACIONES IMPUESTAS.

a).- Hundimientos Diferenciales.

b).- Efectos térmicos de dilatación y de contracción.

3.1.4 DESGASTE Y ALTERACION QUIMICA Y BIOLOGICA

a).- Abrasión y Erosión.

b).- Corrosión y otras formas de intemperismo.

c).- Ataque de Insectos y vegetales.

3.1.5 FUEGO.

3.1.6 EXPLOSIONES.

3.1.7 OTRAS. (Efectos de rayos , pérdida de material por efectos - electrosmóticos etc)

4. CARACTERISTICAS FISICAS DEL TERRENO.

La forma, el volumen y la altura del edificio, así como las previsiones respecto a su infraestructura (movimientos de tierras, cimentación, atarjeas) deben ir en concordancia con el tipo de terreno, sus pendientes, la calidad y espesor de las distintas capas del suelo y subsuelo, su capacidad de carga,etc. para ello es necesario atender a los resultados de los levantamientos topográficos detallados y los estudios de mecánica de suelos y geotécnia, se requiere a la vez las características Hidrológicas del sitio para generar obras de protección o desvio donde se requiera.

El uso específico del suelo localizando sus distintas actividades.

Localización de la flora, características, dimensiones; para generar la arquitectura del paisaje o restricciones que se puedan presentar por la existencia física de estos, justificando su retiro o conservación.

Edificaciones existentes; evaluando su remodelación, restauración o simplemente remozadas.

5.- FORMACION DE UN AMBIENTE CONFORTABLE.

En el sistema deberá contemplar medidas para formar un medio ambiente adecuado al destino del edificio en los siguientes aspectos

5.1 Formación de microclimas sin uso de medios mecánicos.

En la toma de desiciones y en su evaluación se toma en cuenta los factores que se muestran en la fig.1, a fin de permitir en lo posible la formación de un microclima adecuado al uso de los locales sin necesidad de recurrir a medios mecánicos, en el supuesto caso, que las variantes de la fig. 1 no garanticen satisfactoriamente un resultado apropiado, se recurrirá a medios mecánicos para controlar el ambiente.

PERALTES MINIMOS ADMISIBLES EN VIGAS DE CONCRETO REFORZADO SIN COMPROBACION DE DEFLEXIONES

Uso de la viga		Peralte mínimo			
		Ambos extremos libremente apoyados	Un extremo continuo	Ambos extremos continuos	Voladizo
Soporta muros divisorios o está ligada a ellos	En techos	L/12	L/16	L/19	L/5
	En pisos	L/10	L/13	L/15	L/5
No soporta muros divisorios ni está ligada a ellos	En techos ✓	L/18 ✓	L/23	L/29	L/7
	En pisos	L/14	L/18	L/23	L/6

PERALTES MINIMOS ADMISIBLES EN LOSAS DE CONCRETO REFORZADO APOYADAS EN LADOS OPUESTOS, SIN COMPROBACION DE DEFLEXIONES

Uos de la losa		Peralte mínimo			
		Ambos extremos libremente apoyados	Un extremo continuo	Ambos extremos continuos	Voladizo
Soporta muros divisorios o está ligada a ellos	En techos	L/15	L/20	L/24	L/6
	En pisos	L/12	L/16	L/19	L/5
No soporta muros divisorios ni está ligada a ellos	En techos	L/22	L/29	L/36	L/9
	En pisos	L/18	L/23	L/29	L/7

FASES DEL PROYECTO.

1.- CARACTERISTICAS DE UN PROBLEMA.

Una característica de la mayoría de los problemas a los que nos enfrentamos es el gran número de soluciones posibles que pueden tener dichos problemas; dentro de las faces de un proyecto, surgen a menudo problemas, en síntesis, que caracteriza la situación denominada problema: --- ¿Cual es su significado? ¿Que es lo que tienen en común los problemas?.

Probablemente, las respuestas que se les den a preguntas - como las anteriores sean vagas e incompletas. Por lo que no pretenderé - llegar a la interpretación específica y exacta del término sino a las características generales de un problema.

UN PROBLEMA SURGE CUANDO EXISTE EL DESEO DE TRANSFORMAR UN ESTADO DE CONDICIONES, EN OTRO.

Si observamos la fig. 1 veremos en el estado a una necesidad a satisfacer que pasan por la caja negra que podemos interpretar como "Las cosas que hay que hacer". Para llegar a tener la necesidad satisfecha estado B. Surge el problema sí para pasar del estado A, al estado B existen varias soluciones, pués por otro lado cuando todas las soluciones posibles son cualitativa y cuantitativamente iguales, el problema deja de e-- xistir. Por eliminación podemos concluir quse un problema incolucra algo más que hallar una solución cualquiera; requiere encontrar el mejor método para lograr la transformación deseada. A las bases que permiten seleccionar la mejor solución posible se les conoce como el CRITERIO. Bases -- que reaccionan de muy diferente manera.

Volvamos a la fig. 1, si los estados A y B no son identi-- cos, DEBE verificarse una transformación ó DEBEN ocurrir ciertas cosas. En lo sucesivo, llamaremos Restricciones a ese conjunto de cosas que Deben ocurrir o verificarse en una solución aceptable de un problema dado, bien sea por razones físicas, o por decisiones previamente tomadas.

2.- EL PROCESO SOLUCIONADOR DE PROBLEMAS:

Formulación del Problema.

2.1 Procedimiento general para resolver problemas una vez generado el problema.

El primer paso lógico en la solución de cualquier problema, es la definición del problema, entendiendo por definición del problema la definición del problema la identificación de sus características. Posteriormente tendremos la busqueda de las diversas soluciones posibles y por último la tercera etapa del proceso para resolver problemas que es el Proceso de Decisión.

2.2 Proceso solucionador de Problemas:

El procedimiento general, especial para la solución de los problemas tecnológicos usuales, consta de las siguientes fases:

a).- La fase de la formulación del problema, en la que éste se define en una forma relativamente amplia, sin consideración de detalles, y hace incapié respecto a la identificación de los estados A y B. Fig. 2-1

b).- La fase del análisis del problema, durante la cual el problema se define en una forma relativamente amplia. Esto involucra una sintetización , investigación, procesado y descriminación de la información recabada, para así poder determinar las características específicas del problema. Fig. 2-2

c).- La fase de busqueda en la cual se indaga acerca de las diversas soluciones propuestas a problemas similares . Fig. 2-3

d).- La fase de decisión, durante la cual las diversas soluciones posibles logradas se evalúan, comparan y descriminan, hasta que surge la mejor de ellas. Fig. 2-4

e).- La fase de especificación, la cual consiste en una completa descripción de las características físicas y de funcionamiento de la solución elegida. Fig. 2-5

Integrando los puntos del inciso 2.1 con los del 2.2 podremos obtener la secuencia de actividades que involucra el proceso solucionador de problemas y los eventos que unen dichas actividades. Fig. 3

FASES DE PROYECTO:

Una vez integrado el proceso solucionador de problemas; - formulación de problemas, encontraremos la similitud existente entre proyecto y problema.

a).- Existen un gran número de soluciones posibles a una necesidad específica.

b).- Existe un deseo de transformar un estado de condición, en otro.

c).- Se requiere encontrar el mejor método para lograr la transformación deseada.

Si la necesidad de proyecto responde afirmativamente a estos puntos, podemos concluir que proyecto y problema son afines.

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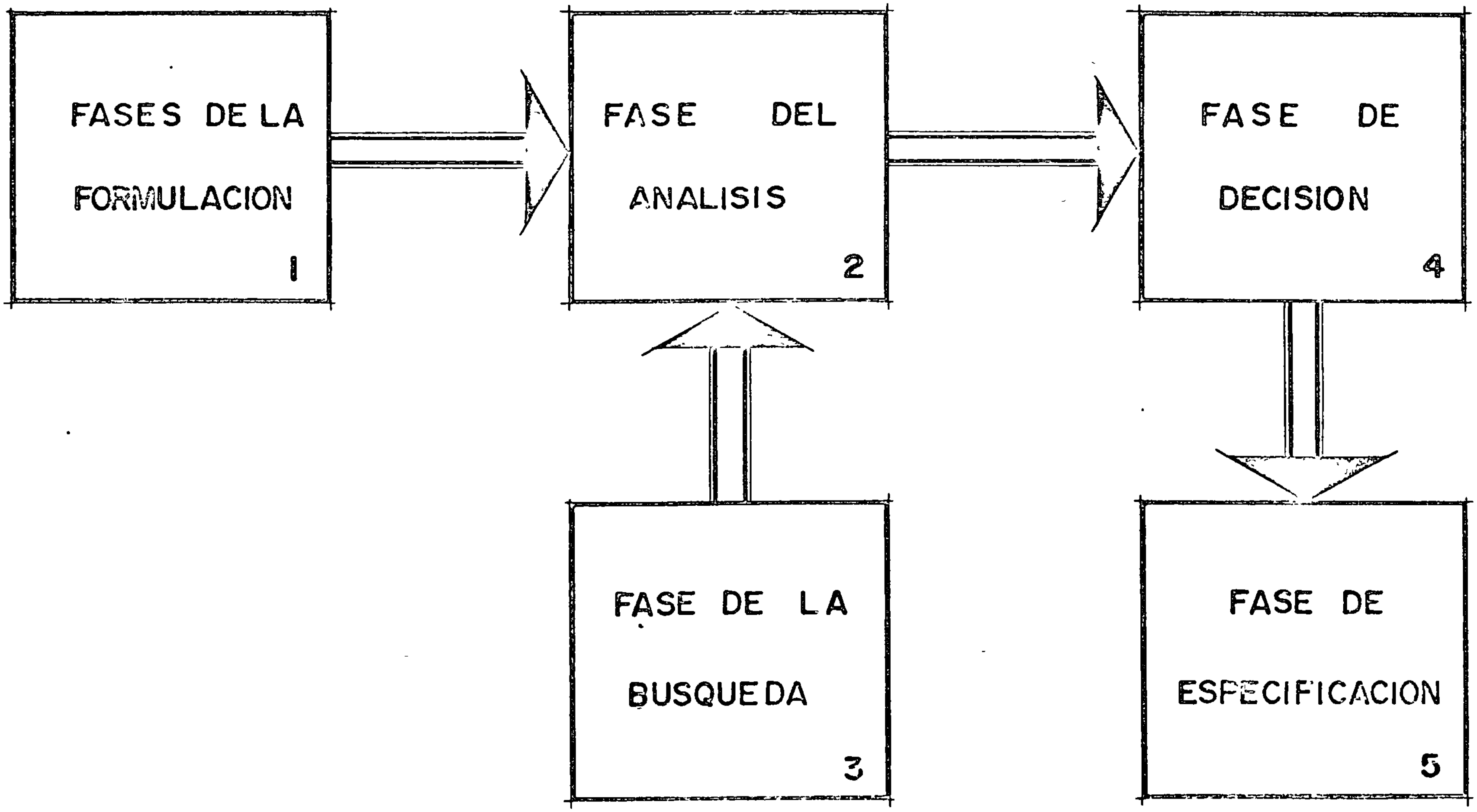
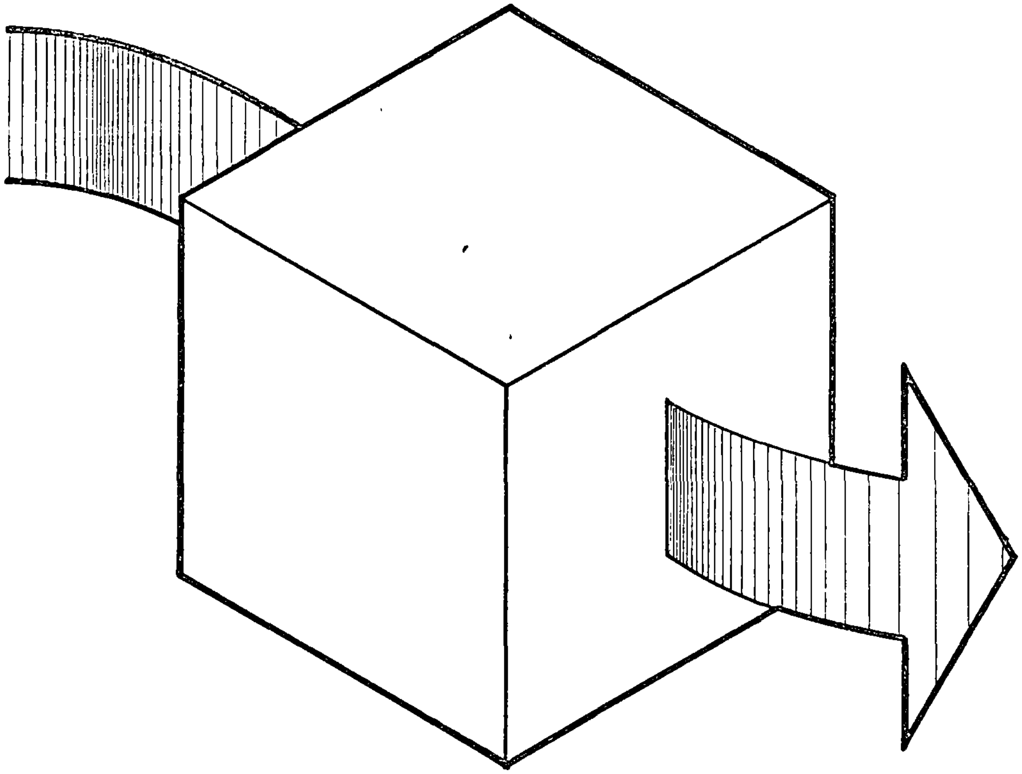
PROCESO SOLUCIONADOR DE PROBLEMAS. FIG. 2.





ESTADO A

- DATOS DE ENTRADA
- INSUMO
- NECESIDAD A SATISFACER

ESTADO B

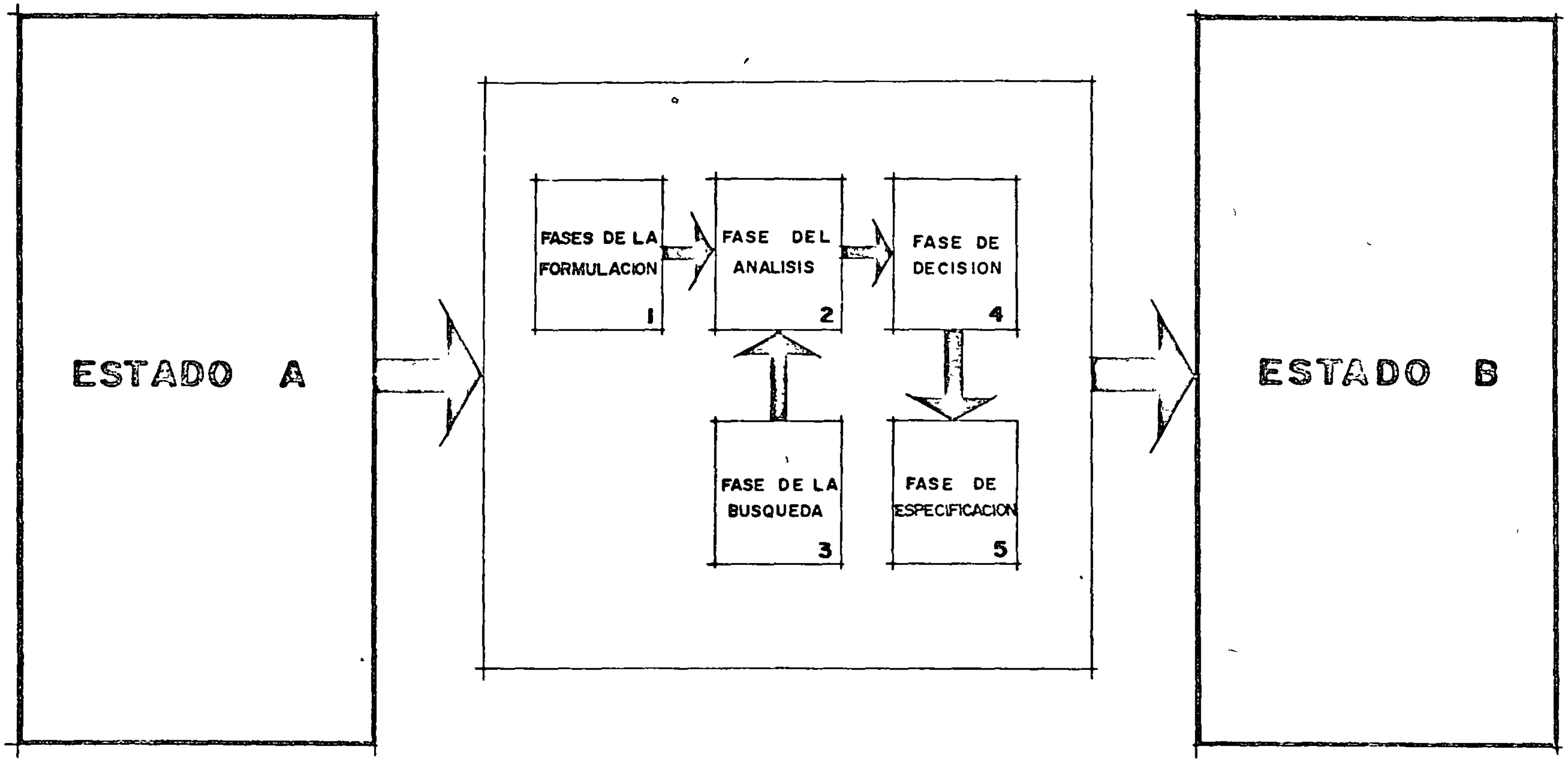
- RESULTADOS
- PRODUCTO
- NECESIDAD SATISFECHA

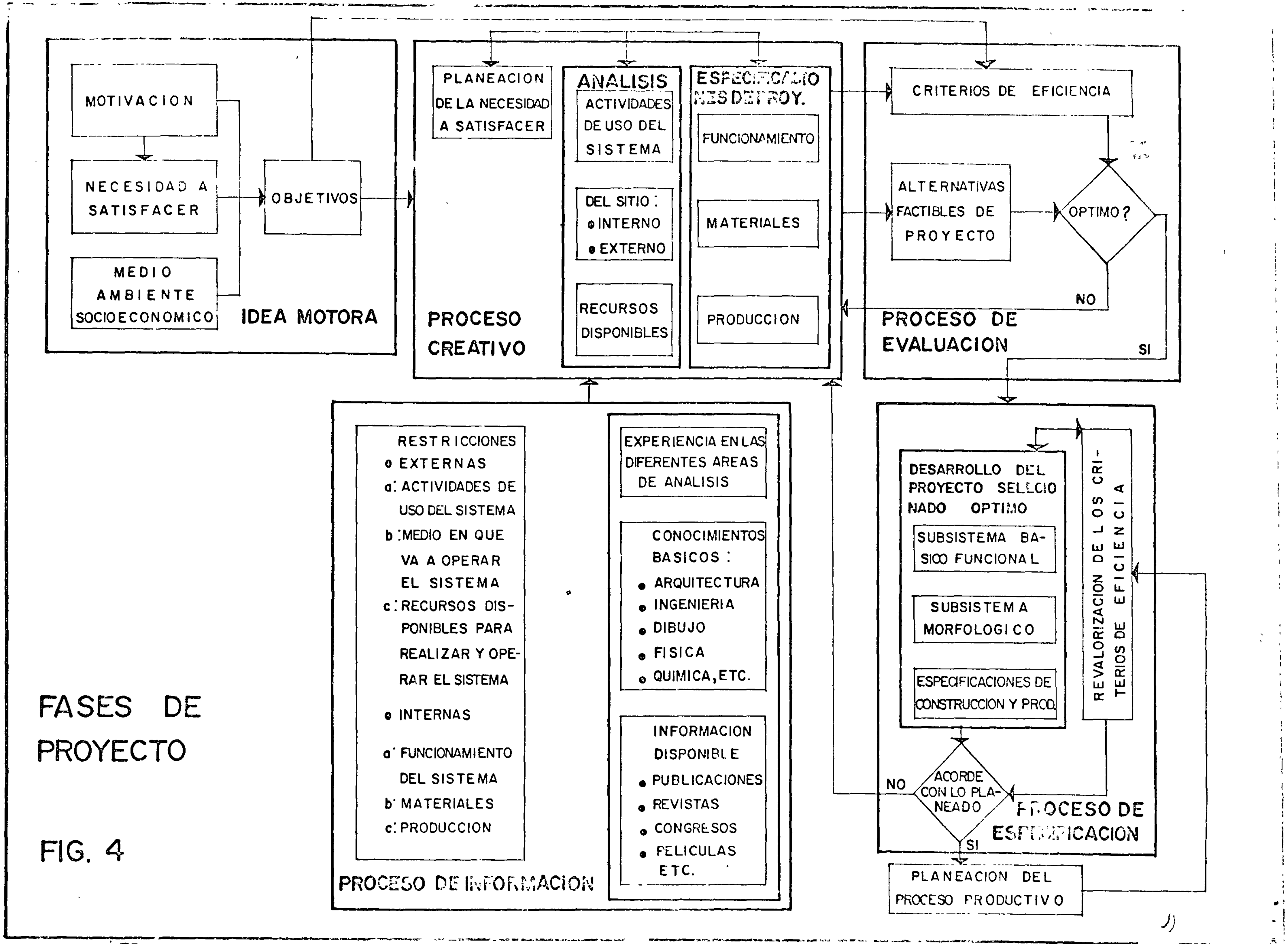
CAJA NEGRA

LA CAJA NEGRA . FIG. I

PROCESO SOLUCIONADOR DE PROBLEMAS: FORMULACION DEL PROBLEMA

FIG. 3





FASES DE PROYECTO

FIG. 4