THE FUNCTION OF TESTING DURING ARCHITECTURAL DESIGN

by

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ABSTRACT

The Function Of Testing During Architectural Design
By Guy Edward Weinzapfel

Submitted to the Department of Architecture on January 22, 1971, in partial fulfillment of the requirements for the Degree of Master of Architecture.

The objective of this study is to explore and clarify the role of testing in the process of architectural design. As the basis of the study, a general definition of testing is developed. Several different kinds of testing are discussed in terms of this definition. Boundaries are outlined between testing and the related functions of problem description and evaluation. And ways in which seemingly useful tests can lead to erroneous conclusions are discussed.

A design experiment is conducted as a means of exploring some of the ways in which a designer employs tests during his search for a problem solution. The experiment indicates that tests are made of three important aspects of the design: of the alternatives generated, of the criteria by which the alternatives are judged, and of the design objectives which the criteria represent.

Based on the experience of the design experiment, a simple computer routine is developed which can aid a designer in testing alternative forms generated by a computer system. The routine is developed as an example of the way in which a common form of testing can be incorporated into a design aid system. The utility of the testing routine is evaluated in relationship to other kinds of testing which designers employ.

It is hoped that this study will be useful to the designer and the design educator by externalizing and providing a tentative structure for a portion of the process which they conventionally employ. Further, the study may be useful to the design methodologist who seeks to develop new tools to aid the designer in his work.

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TABLE OF CONTENTS

Chapter One: INTRODUCTION................................. 6
   Objectives of the Study
   Testing in Design
   The Remaining Chapters

Chapter Two: THE STRUCTURE OF TESTING............... 14
   A General Definition
   Alternate Forms of Testing
      Tabular Comparisons
      Comparison of Forms
      Statements of Preference
      Non-Translatable Tests
   Defective Testing
      Inaccurate Standards
      Irrelevant Standards
      Inaccurate Representations of Form

Chapter Three: A DESIGN EXPERIMENT..................... 39
   The Use of IMAGE
   The Design Problem: A Fire Station
      The Architectural Program
      Circulation: A Major Design Objective
   The Model for Generation
   The Design Process
      Arrangements
      Tests
      Changes to the Model
      New Generation
   Observations

Chapter Four: A COMPUTER TESTING ROUTINE............. 79
   The Purpose of The Routine
   The Test Algorithm
   The Output
   Possible Improvements

APPENDIX................................................................. 94
   Architectural Program For A Fire Station
   P11 Program for Computer Aided Testing

FOOTNOTES............................................................. 112

BIBLIOGRAPHY......................................................... 116
**Table of Figures**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIGURE 1</td>
<td>List of Spaces for the Fire Station</td>
<td>42</td>
</tr>
<tr>
<td>FIGURE 2</td>
<td>Matrix of Generating Specifications</td>
<td>70</td>
</tr>
<tr>
<td>FIGURE 3</td>
<td>Arrangement From First Generation</td>
<td>71</td>
</tr>
<tr>
<td>FIGURE 4</td>
<td>a) Arrangement From Second Generation</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>b) Diagram of Necessary Circulation</td>
<td></td>
</tr>
<tr>
<td>FIGURE 5</td>
<td>a) Arrangement From Third Generation</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>b) Diagram of Necessary Circulation</td>
<td></td>
</tr>
<tr>
<td>FIGURE 6</td>
<td>Diagram of Desired Circulation</td>
<td>74</td>
</tr>
<tr>
<td>FIGURE 7</td>
<td>Arrangement From Fourth Generation</td>
<td>75</td>
</tr>
<tr>
<td>FIGURE 8</td>
<td>Final Computer Generated Arrangement</td>
<td>76</td>
</tr>
<tr>
<td>FIGURE 9</td>
<td>Designer's Sketch of Alternative Arrangement</td>
<td>77</td>
</tr>
<tr>
<td>FIGURE 10</td>
<td>Conceptual Diagram of Solution Spaces</td>
<td>78</td>
</tr>
<tr>
<td>FIGURE 11</td>
<td>Diagram of IMAGE Data Structure</td>
<td>90</td>
</tr>
<tr>
<td>FIGURE 12</td>
<td>Flow Chart of Testing Algorithm</td>
<td>91</td>
</tr>
<tr>
<td>FIGURE 13</td>
<td>Typical Displays of Test Information</td>
<td>92</td>
</tr>
<tr>
<td>FIGURE 14</td>
<td>Diagram of Possible Data Structure</td>
<td>93</td>
</tr>
</tbody>
</table>
Chapter One

INTRODUCTION

This study deals with testing as it is performed in the process of architectural design. It is the result of a study of testing which grew out of a research effort to develop a computer aid for preliminary architectural design. (1.1)

I. OBJECTIVES OF THE STUDY

It is the author's hope that the ideas put forth here will help clarify that portion of design dealing with tests. These ideas might also facilitate the development of design aids capable of assisting the designer in testing his alternative solutions. At a time when much effort is being devoted to developing aids for the designer, a clear understanding of his actual activities, and of the tools he needs to perform those activities, is especially necessary.

The study was not undertaken to prescribe any particular process for the designer. Rather it is the author's belief that no single process could be employed for two problems by one designer, much less by two different designers. The particular functions which are
performed during design, are selected, organized, and performed under the influence of the context of the problem being addressed. It is the problem, the state of the information concerning that problem, the designer's experience, the resources available to him, and innumerable other factors which make it infeasible to prescribe a particular procedure for even the single function of testing.

What the author intends instead, is to develop a general description of what composes a test, to outline a few of the characteristics of testing, to provide an example of the way testing can be employed in design and the impact which it can have on the designer's process, and to develop a simple aid which a designer can use for testing.

II. TESTING IN DESIGN

This study grew from the realization that testing is a very important function of design and a function which could be analyzed separate from the other activities of design. (1, 2) A few examples of how testing can be used in design may make this point clear.

It is often the case that in the process of generating solutions to his problems, a designer develops an alternative arrangement with which he is very pleased. He may not be interested in generating new
alternatives but only in ascertaining how well the present alternative satisfies his original problem specification. In other words, he would like to test his present arrangement against the criteria of his original specification.

As an example, let us assume that an architect has developed a problem specification for a school, and is generating alternative arrangements. Each arrangement may be radically different from the last. At some point, an alternative is produced which appeals to the designer in several ways. The spaces may be organized hierarchically, indicating their functional importance. The overall arrangement might also be very symmetrical or asymmetrical or possess some other order which appeals to the architect. It might lend itself to a simple structural system, and have several other attributes which please the designer for reasons he may or may not be able to identify.

The architect is reluctant to continue his search for basically different design alternatives. He may be willing to make limited modifications to improve the scheme, but he is very reluctant to make large changes in the basic order he sees. It is possible, however, that there is no reason to change the present alternative. It may already satisfy the criteria he has specified. He will therefore want to test the design
against those criteria. If the scheme does indeed satisfy them all, he will probably accept its basic form and begin elaborating it in more detail. If it fails in small ways, he may modify certain portions of the arrangement until it does meet all the criteria, until he has decided that the arrangement will never satisfy the criteria and rejects it, or until he decides that some of the criteria are not significant enough to warrant discarding the design and ignores them.

In order to pursue his design, then, the architect must be able to test various alternatives against the criteria for which they were generated.

SYNOPTIC APPRAISAL

In another situation, the designer may wish to measure an arrangement against additional criteria, criteria he had not previously specified. Obviously not all criteria can be, or even should be, described at the onset of a problem. Many can be discovered only through the process of exploring different alternatives. Even if all criteria were known, it would probably be unnecessarily complicated to generate alternative forms from the complete set; some limited subset of the criteria might be all that is necessary to generate acceptable alternatives. In fact, it can be argued that the "good" designer is the designer who selects the
criteria which cause the most efficient search for a solution. (1.3)

As an example, the generating specification for a school may not deal with the secondary roles which the building is to fulfill. The playing fields might serve as neighborhood recreation areas, and the physical complex might be used for civic events such as PTA meetings. These functions may not be significant enough for use as generating criteria, but they are significant enough to be tested in the light of an otherwise acceptable design.

Many times, secondary test criteria can be brought to light only in the context of a generated alternative. Clients, because they are not versed in the opportunities and limitations they face, often form new goals upon seeing the consequences of their criteria. This is even true of the most sensitive designers.

TESTING FORMS OF UNKNOWN ORIGIN

A third role for testing is typified by the situation in which a designer is faced with an existing design he had no hand in creating, but which he must modify to meet a new use. In this situation, he will want to test how well the design already satisfies the criteria describing that use.

Buildings remodelings are obvious examples of this
condition. Found object sculpture operates at this level, and in many fields objects are created for one purpose which are found to satisfy other roles. In these cases, the designer tests the existing forms against new criteria, criteria for which they were not originally generated.

All of these situations indicate that the designer cannot generate alternative solutions exclusive of testing - that a very large part of the design process lies outside the realm of generation. However, they do indicate that testing can occur exclusive of generation.

The realization that testing was a very important function of design and that it could have a "life of its own" separate from generation, led the writer to examine the nature of testing architectural form, and its role in the process of design. The results of that study are the substance of this report.

III. THE REMAINING CHAPTERS

The remaining chapters can be seen as three different approaches to the subject: as theory, as documentary and as application. Chapter Two discusses testing in a general way. Chapter Three documents an actual design study, and Chapter Four describes an application of the experience gained from that design study to the development of a computer aid for testing.
In order to establish a common basis for further discussion, Chapter Two, "The Structure of Testing", develops a general definition for a test as related to the process of design. It discusses what factors are necessary to form a test, how they are derived, how they operate and interact and what results they give. Some of the different kinds of tests which a designer performs are discussed in terms of this general definition. It is shown that both the representation of the design being tested and the state of the objective which it is to achieve will affect the way in which the test is performed.

In order to identify the boundaries of testing and to distinguish it from other, closely associated activities, brief descriptions are given for measurement and evaluation of design. Other factors, such as testing's facility and complexity are also treated in an effort to clarify the territory included within the boundaries of this function. The final part of Chapter Two addresses the relationship between the objectives which the design must achieve and the tests which can be made of the proposed solution. It outlines the interdependencies between the different elements of the test, the state of the alternative and the resources of the designer. And it discusses how faults in any of those elements can render results which are
inappropriate, misleading or ineffectual.

Chapter Three, "A Design Experiment", documents an actual design study which was performed to illustrate and enlarge upon the issues introduced in Chapter Two. The criteria are outlined for selecting the project used in the study, a fire station. Since the design alternatives were generated by a computer system, the reasons for using the computer, as opposed to designing in a conventional manner are discussed. The documentation of the design process itself records what steps were taken, what tests were performed, and how the results of the tests caused modifications in the designer's strategy.

Chapter Four describes "A Computer Testing Routine" which can be used for testing the alternatives generated by a computer system. This routine was developed in response to the experiences of the design study. It uses many of the procedures in a presently existing system. Some of the different kinds of testing are compared to the developed routine, and some proposals are made for expanding the routine to include a wider range the designer's needs.
Chapter Two
THE STRUCTURE OF TESTING

A test is a comparison between the actual value of some aspect of the design and some value which it is supposed to achieve. The results of the comparison are acceptable within certain limits and unacceptable beyond those limits.

AN EXAMPLE

In order to introduce the basic elements composing a test, an example of a typical design test is described below. Following the example, a general definition of a test is derived, using illustrations from the example to clarify its concepts.

Assume an architect is designing an office building for a developer. One of his client's primary objectives is that the building should make as much profit as possible. Knowing that the ratio of rentable to non-rentable floor area will significantly influence the ultimate profit return of the building, the architect and client seek a ratio which will give the greatest probability of a high return. They know that this ratio is not the only factor bearing on profit, but
that it is significant enough to be carefully considered.

From his past experience, the architect has found that few buildings can be expected to achieve a ratio greater than six to one, but that most are capable of at least four to one. The client's experience in real estate development shows that buildings with a ratio less than 3.5 to 1 will return a marginal profit even when fully occupied, and that those with greater than 5.5 to 1 fail to do much better because of high vacancy factors caused by the tenants' feelings of being "packed like sardines". The optimum return appears to occur around 4.5 to 1. They decide, then, to seek a design which will have a 4.5 ratio. They will be satisfied with nothing less than four, and will avoid alternatives higher than five and a half.

In seeking a basic arrangement for the building, the architect generates several alternative schemes. Each shows the basic configuration of spaces in the building. Corridors, offices, elevators and mechanical equipment rooms are all roughed in. He determines the area ratios for each scheme by the process of subtracting the total rentable area from the gross area.

The ratios of each alternative scheme are compared to the standard he hopes to achieve. Those schemes with ratios greater than 5.5 or below 4 are set aside. Some,
in fact, are rejected. Others are modified in hopes of meeting the standard.

In accepting or rejecting the alternative schemes, the architect is basing his judgment on the results of tests. These tests are typical and embody the general form and the basic conditions of testing. To clarify discussion in the remainder of this study, a specific definition and notation is given below.

I. A GENERAL DEFINITION

A test, T, may be defined as a comparative function, f, between some measurement, M1, of a form, F, and a measurement, M2, of an objective, O, which is acceptable within some tolerance, t.

\[ T = f( M1(F) \ M2(O) \ t) \]

THE FORM, F, is the description or the representation of a possible real form. In the test example above, the form is the alternative scheme for the office building. It is actually a representation of a possible form that might ultimately be built and not the reality of the building itself.

For some tests the form may also be thought of as the larger environment within which the building would be only a part. This larger conceptual frame is necessary in order to test those aspects of the design
which lic partially cutside the description of the building being designed. As an example, a designer who would test the solar exposure of a building, would have to have information concerning the location and shape of surrounding buildings, the range of positions which the sun would follow over the year, the climate of the region, as well as the orientation and shape of the building itself.

THE OBJECTIVE, C, is the goal for which the environment is being tested. Unlike the form, it is normative in nature. It states how the form should exist rather than how it does exist. In the example, the objective states that the building "should make as much profit as possible."

M1 and M2 are the functions which measure the form and the objective, respectively. They are noted differently to indicate that their measurement techniques and the data they rely upon are not necessarily the same. In the example, the actual ratio of the form is determined from a function which scales the various dimensions of the form and by mathematical operations computes the actual ratio of the proposal. The objective ratio derives from the past experiences of the client and the architect.

The measurement of the form derives an attribute, "a", some value which may be attributed to the form.
\[ M_1(F) = "a" \]

The measurement of the objective derives a standard, "s", which the form should achieve.

\[ M_2(C) = "s" \]

In the test example, the value of the standard was 4.5. The value of the attribute varied for each alternative form.

**The Tolerance**, \( t \), is the allowable deviation between the attribute and the standard. It is the amount of misfit which the designer feels he can accept between the design and its objective. In the example, the tolerance permitted a range one unit higher and one half unit lower than the optimum ratio of 4.5.

The tolerance is perhaps the most flexible aspect of the test. Many tests will maintain the same objective and standard throughout a design, while the tolerance is varied from very loose to very specific in keeping with the detail of the alternatives developed. For example, the main entry to a building may at first be acceptable anywhere on the north facade. But as the arrangement of the building's interior, and its immediate environment, becomes more specific, there will likely be only one acceptable location for the door.

The test function, \( f \), is composed of two operations. It first compares the attribute of the form and the value of the standard, thereby deriving a third
measure, the difference between the two. The function then compares that difference with the tolerance, \( t \), and passes or fails the test on the basis of that comparison. Thus, the form of a test is: 1) the measurement of some aspect of the proposed form, \( M_1(P) \), which results in a value of that aspect or attribute, "a"; 2) the measurement of that same aspect of the objective, \( M_2(O) \), which results in a value for a standard, "s"; 3) the comparison of those two results, "a" and "s", resulting in a measure of their difference; 4) the comparison of that difference with the tolerable difference, \( t \); and 5) the passage or failure of the test derived from that final comparison.

II. ALTERNATE FORMS OF TESTING

Not all testing is the mathematical comparison of quantifiable values, such as illustrated in the example above. Many different kinds of tests are possible, dependant upon the state of the form being tested and the type of objective it is to achieve. That is to say that tests differ in kind due to the varied operations and procedures they require. Diverse forms of measurements are required by the many modes in which a form may be represented: as a mental image, as a verbal description, as a drawing, as a model or as a final
constructed reality. The type of objective, and its standard, will also influence the kind of test performed. Many objectives, such as lighting will necessitate reference to some pre-established table for quantifiable standards; "The light level should be 75 footcandles". Others will require an indication of qualitative preference, yet others will be impossible to externalize, or translate into any explicit form. In short, different kinds of testing are produced by the test's two major arguments and the procedures used to measure and compare them. Some of the different kinds of tests possible are discussed below.

**TABULAR COMPARISONS**

A common type of test is the comparison of some aspect of a design to some tabulated or quantifiable standard. In tests of this nature, the standard is derived from a table, where M2 is the search of that table, or the recall of its previous search. Examples abound as entire volumes have been devoted to recording such factors as hearth/flue area ratios. (2.1) And nearly every profession and trade, as well as most federal, state, and city board, regardless of how remotely connected with building construction, produce copious guidelines for the designer.

An extension of this kind of testing is made by substituting an equation from which the standard can be
calculated. Rules of thumb, such as "The riser plus twice the tread should equal 29 inches", are more convenient, yet produce the same effect as tables. The derivation of structural and mechanical equipment standards are extensions of this approach.

Tests of this type are easily described, usually based on mathematical calculations and comparisons. Their results are also quite precise. And the tests can be performed by even the most superficially informed.

**COMPARISON OF FORMS**

Another common kind of testing employs the comparison of two forms. In this case, the standard is intrinsic within another form or its representation which is known to be acceptable or to have certain desirable characteristics. The test is based upon a comparison between the "objective" form and the form under question. For example, a designer might develop a scheme in which a very obvious hierarchical circulation system is evident. He can test his other alternatives against this scheme to determine if such clear circulation had been generated unnoticed before or to see if the other forms could be easily modified to incorporate it. By an extension of the notation above, such a test can be represented as:

\[ T = f(M1(F1), M1(F2), t) \]
where \( F_1 \) is the alternative being tested, \( F_2 \) is the objective form (in this case, the scheme having the clear circulation), and \( M_1 \) is a common process of measuring the two forms (here a visual inspection).

The objective form, \( F_2 \), need not be otherwise related to the design problem for which the test is conducted. It might as easily be an existing building, or an abstracted pattern, such as a grid, a tree, or a wheel. It need only embody or represent the objective being tested. Diagrams are commonly used as simple representations of form objectives.

A frequent variation of this kind of test uses the objective form as a "threshold standard", some statement of a least acceptable level, which may be combined with an indicated direction for improvement: "The facade should be at least as imposing as Bonwits — hopefully more so"; or "This building must be at least one story higher than the Prudential." Obviously threshold standards are applicable to other kinds of tests as well.

STATEMENTS OF PREFERENCE

Most standards may be seen as statements of someone's preference. Certainly the tabulated standards
for heating and lighting were determined by the careful synthesis of many peoples preferences. However, most standards are not primarily identified with this characteristic.

But certain test criteria gain their identity solely from the objectives of some actor central to the design problem, the client, the user, the designer, etc. The "Observations" in the Fire House Architectural Program in the Appendix contain many examples of preference statements; "There will be a flagpole."

Many preferences can not be foreseen prior to the generation of alternatives. As a result, many tests in this category are performed by using the design alternative to extract the preference of those involved. In such cases, the distinction between the elements of the test become blurred, for in a sense, the alternative is measuring the clients desires, which in turn pass or fail the scheme.

NON-TRANSLATABLE TESTS

At the opposite extreme from tabular comparisons are tests in which the standard, and even the objective it represents, cannot be made explicit, and in which certain aspects of the alternative cannot be universally understood. A designer may continue to search for alternatives while not being able to explain his reasons for rejecting those at hand.
It is perfectly understandable that certain design goals will be inexplicit, since the designer's image of his problem is very rich and derives from many diverse sources. His problem image goes well beyond the objectives stated or inferred by his client to encompass his grasp of technological, economic, and political systems - their resources, limitations, and potentials. Further, the designer's image of his problem is based in the culture and society of which he is a product, and is impacted by his previous design experience. These and many other factors combine to form a very rich perception of his problem.

Moreover, both the medium in which the design is addressed and the discrepancies between that medium and the consequent reality of the built form pose issues which cannot be externalized in all forms of communication. The homily, "One picture is worth a thousand words", is not entirely accurate; words will never recreate the picture. In a similar way, many of the attributes and relationships conveyed by representations of the design cannot be communicated adequately in any other medium. Conversely, because of his familiarity with both his mode of representation and the buildings which result, a designer may sense information from his representation of a design which is not grasped by others.
As a consequence of the designer's diverse perception of his problem and the medium in which it is explored, many tests will be conducted without the possibility of externalizing either their process or their results. As opposed to tabular comparisons, tests of this kind can be performed only by the designer, himself.

**MEASUREMENT: AN ELEMENT OF TESTING**

For many, a certain ambiguity exists regarding the meaning of the word "test". Testing is often used to refer to functions which are not actually comparative in nature. For example, determining the height of a space or the number of intersections on a corridor are considered by some to be tests—testing the state of the design. For purposes of this paper, however, determining the state of some aspect of a design will be referred to as a measurement, or a description. Only when information concerning the design is used for a comparison with an objective can the function be identified as a test.

**TESTING: AN ELEMENT OF EVALUATION**

A similar confusion exists regarding the distinction between testing and evaluation. Whereas a test is the comparison between the actual state of a certain design alternative and the state necessary to
satisfy a single objective, evaluation is taken to mean either 1) the assessment of a design alternative's worth based upon the comparison of that alternative to a comprehensive set of objectives for the project, or 2) the comparison and ranking of several design alternatives according to their relative satisfaction of a set of criteria.

In both forms, evaluation must determine the relative significance of conflicting goals based upon the preferences (the value system) of some person or persons, i.e. client, user, designer, etc. Evaluation assigns the worth of a particular design alternative; it ranks the relative "goodness" of several possible designs. In doing so, evaluation may employ testing in much the same way that testing uses measurement. But evaluation poses conceptual and procedural questions which are well beyond the scope of testing and this study.

**THE FACIILITY OF TESTING**

None of the conditions which determine that a certain function is a test (as opposed to a measurement or evaluation) have anything to do with the degree of difficulty involved in performing them. A test can involve as little effort as a simple visual inspection or can require a complex and arduous mathematical calculation. Perhaps most design tests are the result
of brief visual observation, since the state of a design is usually described by a drawing or model. But the detailed computations necessary to determine an expected foot candle level and compare it to the intended standard do not make that function anything more or less than a test.

III. DEFECTIVE TESTS

Several factors can cause tests to be ineffective, thus leading the designer to erroneous conclusions. Two major elements of a test, the description of the form and the derivation of the standard, influence the effectiveness of the test. This section will discuss: the ways in which inaccurate standards can cause useless results, the relationship between irrelevant standards and meaningless results, and the limitations of tests which measure a representation of a form rather than the actual form.

INACCURATE STANDARDS

If the value of a certain attribute matches the standard against which it is being compared, the test is passed. If the standard itself is inaccurate, however, the result, and hence the test may be meaningless.
Standards should be determined which accurately represent the higher level objectives for which the test is being conducted. Any standard which fails to accurately represent its objective will cause misleading results. For example, a design may be sought which facilitates easy installation of plumbing. Chases of less than 6 inches may, in actuality, be less than the required clearances of some fittings and thwart that objective. A standard of 5 inches would be inaccurate and tests based on that standard would be misleading.

There are many reasons for which standards might be inaccurately derived. Among them are: 1) standards which are not easily quantified; 2) standards for which no universal value has been set, either because the objective is unique or because insufficient study has been done to codify them; 3) standards which have become obsolete.

Many standards are especially difficult to quantify. Qualitative objectives often fall in this group. Privacy, openness, spaciousness, cheerfulness are a few of the goals with which an architect might be faced. They convey attributes which are very important in any design. Unfortunately, their value or meaning is subject to interpretation. A client, seeing the first designs for his home, might realize that his conception of privacy and that of his architect are quite
different.

The designer must suspect the standards he might establish on the basis of qualitative objectives. In such cases, however, he may be aided by a special application of testing. By presenting a range of design alternatives to his clients, the architect can elicit a response as to how well each achieves privacy or spaciousness. In this way, he can begin to get a picture of his preferences, and be able to more accurately place the value of the standards.

Some standards, though quantifiable, are difficult to measure accurately in the absence of the people for whom they are created. Often, the designer cannot directly contact the people for whom he is designing. In these cases, he will lack the information regarding preferences. Inaccurate standards will be difficult to avoid. An excellent example of such a case occurred at the Seattle World's Fair.

Several of the science displays at the fair were very complex and required abundant time and effort to be understood. It was observed, however, that the average visitor examined the displays for no more than a minute, and that very few visitors remained for more than five minutes. When asked why the displays had been so elaborately contrived, the designers responded that the intent was not to attract only the casual fair goer, but
also the serious student of the subject being displayed. The designer explained that the display had been organised to offer information to such a student for as long as an hour.

The designer had conjectured the existence of the serious student, and tested the display's content on the basis of his existence. In fact, no such student attended the fair, and the displays were too complex for the average visitor who did come. In effect, the standards which the designer had met were inaccurate. (2.2)

Several techniques are available which can assist the designer when standards must be set in the absence of those for whom they are created. They may be predicted by the designer from his own experience or from his empathy with the user. But the possible shortcomings of conjecture are seen in the example of the fair displays. Experiments of pilot situations, and case studies of existing, analogous situations can be very useful. These techniques have been covered in detail in numerous sources, and are beyond the scope of this study.

Inaccurate standards also occur because shifts in preference make them obsolete. In many cases standards which have been very accurately determined will over long periods of time, (in time scales larger than the
schedule for any design project) change and invalidate their usefulness. For example, housing standards which were accurate twenty years ago are no longer adequate today.

Even within the time scale of a design, client preferences may alter enough to invalidate certain standards. This may occur out of the resolution of conflicts between standards or because of the appearance of new alternatives.

IRRELEVANT STANDARDS

Standards may be accurately measured, but they may be irrelevant to the objective sought; they may be incomplete, failing to account for additional, dependent standards; they may also be inadequate, failing to account for all the factors they influence.

Standards, though accurately measured for one context, may be irrelevant to the objectives they serve. As an example, low income housing guidelines have been criticized as irrelevant for the people they serve. The professed objective of the guidelines is to insure adequate housing for the needs of low income families. They are developed on the basis of experiences with middle class families, and set minimum standards for living rooms, dining rooms, kitchens and so forth. Unfortunately, kitchens, dining and living rooms fail to
reflect the actual life styles which lower income families pursue. The standards are irrelevant to the needs of the users, not simply inaccurate. Whether the living room is 500 or 600 square feet actually makes no difference. The spatial context of the standards does not "fit" the life style of the users.

Lack of sufficient qualifications can also make an otherwise meaningful standard irrelevant to its objective. Many standards do not stand alone. They are actually only one factor of networks of interrelated criteria. Alone they may seem very realistic and useful. They may even give reasonable results when considered alone, if their dependant criteria happen to be satisfied as well. However, conditions change and the architect is not aware of one standard's dependancy upon others, the results of any number of tests can become invalid.

Numerous examples of interdependant criteria exist. Take for example, the "climate" of a school, where a good environment for teaching is sought. The standard for the heating and air conditioning might require that the temperature be capable of maintaining 72 degrees in the room at all times. This seems reasonable since many experiments have shown that a temperature of 72 degrees is most universally satisfactory. The building is designed and the heating system meets the temperature
standard. Unfortunately, the students and teachers complain about the heat. The answer turns out to be the fluctuating humidity. The environment failed to be satisfactory, even though the temperature criterion was met. This is a very common situation one standard being highly dependant upon another. Unless the complete network of interrelated criteria are all satisfied, no number of successful tests on one criteria will produce meaningful results.

In these situations, the network of interdependent standards is best stated as a "complex" criterion. Perhaps even a range over which the set is satisfactory will be necessary to insure effective results. The temperature and humidity relationships might actually indicate a range of satisfaction from 80 degrees and 15 per cent to 65 degrees and 80 per cent.

Just as several standards might be interdependent for the satisfaction of a certain criteria, so also might those same standards relate to other criteria which would further constrain them. For example, the temperature/humidity standard necessary, above, may be satisfactory for comfort and therefore insure a good climate for learning. But good health might also be strongly related to a certain range of humidity, while the temperature range for laboratory conditions might be additionally restrictive. Therefore, the designer would
not only have to develop a range of possible temperature/humidity standards for good learning but would have to check their relevance against the criteria of good health and acceptable laboratory conditions, as well.

INACCURATE REPRESENTATIONS OF FORM

The two sections above discussed the ways in which invalid standards can cause invalid tests. Similar problems occur from the limitations of measuring representations of the form rather than the actual forms themselves.

Several factors make it necessary to design buildings by means of drawings, models and other representations of reality. The size of the projects, the resources required to build them, and several other factors make it infeasible to design most buildings in ways similar to painting and sculpture. The restrictions imposed are often severe.

The conditions which will actually occur in the real building can only be estimated and assumed in its design. The uncertain nature of these assumptions may cause severe inaccuracies in design. For example, the wind forces for which a building is designed are only assumptions. The building can be designed to withstand these loads, but in actual fact the winds may be
substantially higher and cause the building to fail. It is because of just such uncertainties between reality and its representation that safety factors are set so high.

Limitations in accuracy are also due to discrepancies between the designer's specifications for the building and the constructed reality in its final form. Highly specific, very cautiously prescribed representations will always differ from their final realizations. For example, 10'-4 1/2" floor to floor dimensions may be exactly specified in the contract documents. When the building is constructed, however, the dimension will certainly differ from that measure to some extent. Often the difference is inconsequential. But often, as in structural design, the variance is quite critical.

Measurements of representations may be invalid for reasons other than the discrepancies between designed and built values. They may be incomplete as well. Every representation, short of the actual artifact it models, contains only a limited description of the form. This is true by definition. If it contained all the information of the form it would be the form. As a result, measurements of a representation often exclude significant information. And tests based on incomplete measurements may lead to invalid results. Unknown
Numbers of architects have designed doors which, from the plan, appeared to open freely, but which were actually constricted by overhangs or elevated projections. Tests for adequate egress were satisfied by the information taken from the plan, but they were most invalid in reality.

One architect in the Southwest was disappointed during the construction of a department store he had designed. He found that a gusset plate which supported a mezzanine girder passed six inches into the clearway of an elevator shaft. All his checks of the drawings had been insufficient to show the situation which existed in reality.

Many qualities embodied in the form of an actual building are more than the sum of their quantifiable measures. And representation of the building are inadequate to convey these qualities. The reverberation time of a concert hall can be closely predicted from the drawings. The background noise level can be determined. The absence of echoes and flutters can be virtually assured. In sum, all the quantifiable factors for good hearing can be validly tested. And yet the hall may still be an acoustical disappointment. This has been the result in more than one case. This type of failure is not due to uncertain assumptions, or faults in the construction. Rather, this type of failure
results from qualities which cannot be conveyed in the abstract.

SUMMARY

The discussion above points out many of the ways in which the results of tests might be invalid. The list is not complete, but it does indicate a few of the broader categories of failure: inaccurate, irrelevant and inadequate standards as well as inaccurate and incomplete representations of reality. The designer, in order to conduct a test, must actually test the validity of the parts of the test and be cognizant of their limitations. He must understand how his standard was derived, what data it was based upon. He should be able to detect those norms which are inaccurately measured or which have become obsolete, either because of changes in his design objectives or because of changes at levels different from his design project. He should know which standards stand alone and which are valid only in the context of others. The designer should have a sense for the appropriateness of a standard to his objectives and know how well it reflects the many factors it may affect.

Further, the designer must be alert to the possibility of significant discrepancies between the representation of his design and its subsequent reality. To be aware of these factors and their significance, the
designer must constantly monitor the arguments of his tests during the design process and review the validity of their consequences in the final reality of the building.
Chapter Three
A DESIGN EXPERIMENT

In order to illustrate and expand upon the issues discussed in the preceding chapter, a small design problem, a fire station, was studied. A case study approach was used for this experiment in order to explore how tests are actually performed, and how several interdependent tests are often necessary to provide adequate analysis of a given objective. The case study was also used to explore the ways in which tests affect the design process, and to clarify what kinds of tests, and what form of results are useful to designers.

Alternate design solutions were generated for the problem by the computer design aid system, IMAGE. (See footnote 1.1) These design alternatives were tested by both conventional and computer aided processes. Some observations regarding the kinds of tests made during the design study are given at the end of the chapter.

THE USE OF IMAGE

The experiment was conducted with aid of the IMAGE system for several reasons. First of all, because of
the nature of the computer system, the different steps taken during the design would be very explicit. Since the computer system operates on a very specific, though limited, set of information, and since it operates only to generate form alternatives, both the state of the information and the design functions being performed would be clearly known at all times.

Since IMAGE had no testing capabilities at the onset of the study, the tests would be performed in a conventional manner, separate from the generation of the alternatives. This would further isolate the testing function and prevent its confusion with other operations.

It was hoped that some portion of the tests could be computerized during the later stages of the experiment - that the experiment would help identify those tests which were most suitable for computer applications, either because of their recurrance, the designer's need for accurate results, or because of their difficulty. As it happened, the study did point out a need for a limited testing routine which led to the development of the procedure described in Chapter Four.

I. THE DESIGN PROBLEM: A FIRE STATION

A fire station for Boston was selected for the
study because it was a relatively well defined architectural problem, whose major goals were clearly understood. Those goals, of course, were to provide housing for a squad of firemen and to provide maximum egress from all parts of the housing to the fire fighting apparatus. The official objectives and requirements of the problem were set forth in an architectural space program which was standard for all fire stations in the Boston area. A list of spaces specified in the program is given in Figure 1 on the following page. The architectural program is included in the appendix. (3.1)

The fire station was also selected because it was a relatively small problem, and a problem for which there appeared to be only a few acceptable design alternatives. That is, because of the limited number of spaces, and the emphasis of a single function, only a limited number of basic arrangements could be expected to satisfy the problem. This made the fire station a particularly good problem with which to study testing, since the standards of "good fit" between design and objectives could be clearly described.

THE ARCHITECTURAL PROGRAM

Though the architectural program was typical of those used for the design of all fire stations in Boston, and though it was considered to be fairly
FIGURE 1: LIST OF SPACES FOR FIRE STATION

<table>
<thead>
<tr>
<th>Function</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparatus Room</td>
<td>2,800</td>
</tr>
<tr>
<td>Patrol Room</td>
<td>120</td>
</tr>
<tr>
<td>Washroom</td>
<td>25</td>
</tr>
<tr>
<td>Hose Drying Tower</td>
<td></td>
</tr>
<tr>
<td>Hose Store Room</td>
<td></td>
</tr>
<tr>
<td>Dousing Shower</td>
<td></td>
</tr>
<tr>
<td>Clothes Drying Room</td>
<td>300</td>
</tr>
<tr>
<td>Oil Stove</td>
<td></td>
</tr>
<tr>
<td>Generator Room</td>
<td></td>
</tr>
<tr>
<td>Boiler and Mechanical Room</td>
<td></td>
</tr>
<tr>
<td>Provisions for Air Compressor</td>
<td>545</td>
</tr>
<tr>
<td>Engine Dormatory</td>
<td>700</td>
</tr>
<tr>
<td>Ladder Dormatory</td>
<td>700</td>
</tr>
<tr>
<td>Firemen's Washroom</td>
<td>150</td>
</tr>
<tr>
<td>Firemen's Shower Room</td>
<td>150</td>
</tr>
<tr>
<td>Locker Room</td>
<td>650</td>
</tr>
<tr>
<td>Engine Officer's Room</td>
<td>315</td>
</tr>
<tr>
<td>Ladder Officer's Room</td>
<td>315</td>
</tr>
<tr>
<td>Officers' Wash and Shower Room</td>
<td>250</td>
</tr>
<tr>
<td>Kitchen-Dining Room</td>
<td>320</td>
</tr>
<tr>
<td>Recreation Room</td>
<td>480</td>
</tr>
<tr>
<td>Linen Closet</td>
<td></td>
</tr>
<tr>
<td>Stationery Store</td>
<td></td>
</tr>
<tr>
<td>Janitorial Cleaning Closet</td>
<td></td>
</tr>
<tr>
<td>Household-Utility Supplies Closet</td>
<td></td>
</tr>
<tr>
<td>Janitorial and Cleaning Store</td>
<td>205</td>
</tr>
<tr>
<td>Two Fuel Tanks</td>
<td></td>
</tr>
<tr>
<td>Gasoline Pump</td>
<td></td>
</tr>
<tr>
<td>Front Apron</td>
<td></td>
</tr>
<tr>
<td>Parking for 25 Cars</td>
<td></td>
</tr>
</tbody>
</table>
comprehensive, it specified only a minimum number of form goals, most of which dealt with room sizes and adjacencies. While the activities planned for the different rooms were labelled, they were not elaborated upon. However, room furnishings, equipment and mechanical services were outlined in some detail. Optimal or satisficing dimensions were specified only for equipment areas, such as the Apparatus (fire engine) Room. Qualities were described in terms of mechanical equipment requirements, maintenance characteristics, water drainage, and heating/ventilating requirements. Only eight form-specific requirements were actually given, though many other formal relationships could be implied or were taken for granted.

The needs of the fire fighting apparatus were in many ways described more elaborately than those of the firemen. Two scale drawings showed the turning radius of the vehicles and the dimensions to be allowed for their parking. Several recommendations were given for the sizing, protection and operation of the Apparatus Room doors. The typical preoccupation with machinery and its operation was evident throughout the fire house program, while the physical, social, and psychological needs of the men using the fire house were seldom directly addressed. (3.2)

The lack of comprehensive documentation of
functional requirements is not unusual. When compared to most architectural space programs, documentation of the fire station is one of the more complete. And, it was for the abundance of this documentation that the problem was selected. (3.3) Voids in the fire station program point out the necessity for the designer to acquire additional information on his own. This information can come from many sources: the architect's past experience, documentation of similar projects, conferences with the client, and so forth. In this case, most of the detailed information relating to the individual activities and their settings was obtained through extensive discussions with the fire department personnel and observation of operations at several existing stations. This information was gathered by architects who had designed a station, and was made available for this study along with the architectural program. (See footnote 3.1)

CIRCULATION: A MAJOR DESIGN OBJECTIVE

Because of its importance to the success of the fire station, circulation was identified as a primary objective of the problem. Unfortunately, the architectural program's description of circulation was typical of the program as a whole; it was sparse at best. Circulation was mentioned explicitly in only ten cases. These references were usually general in
character: "A two story building lends itself better to rapid alarm generated circulation than a single story building." The few detailed specifications dealt more with maintenance than with operation: "Floors should not be waxed as firemen in a hurry, moving quickly, and dressing as they travel are in danger of slipping."

Despite the general recommendation that "emergency routes to the vehicles be direct and free from obstructions", no explicit description was given of which areas those emergency routes should and should not connect. And while at least some attention was given to emergency circulation, none was given to non-emergency use, such as between the dormitories and recreation room.

Though the criteria of good circulation had not been adequately specified in the architectural program, the additional information passed on by the architects of the project and available in architectural journals was more than sufficient to make the requirements clear.

Most importantly, no two major routes of emergency circulation could cross one another. This was true for the apparatus as well as the firemen. A path in front of a fire engine would be ridiculous. Secondly, paths from any of the major spaces to the apparatus should be as direct as possible; it should be possible to get from any room to the Apparatus Room without going through
more than one other space.

Requirements for non-emergency circulation were much less important. It was desirable that the officers' rooms be accessible without passing through the firemen's quarters. It was also necessary to move easily from the pumping engine to the Hose Tower for handling, drying and storing the hoses. Public circulation was to enter the station in clear view of the Patrol Room and be kept from penetrating the station too deeply. The Restroom was seen as the major public destination (after the Patrol Room), and was therefore to be kept to the front of the station. The Recreation and Kitchen-Dining areas were to be equally accessible for both the ladder and engine crews. This factor could be judged by the distance and complexity of the paths from each group's quarters.

Several of its general characteristics made circulation an especially suitable objective for emphasis in the design experiment. The need for convenient circulation is an objective common to all architectural problems. Circulation is also complex enough, embracing a variety of components and characteristics, to require many tests. No single factor, regardless of how satisfactory it is tested, can guarantee the overall acceptability of a circulation system. Rather, a designer must test his circulation
against a wide range of interdependent factors: the length of paths, the sequence of spaces they join or exclude, as well as the interest, clarity, and directness of the circulation network. Each of these factors could, in turn, depend on the satisfaction of many other criteria. Clarity and directness, for example, might relate to the number of interconnections between paths and the number of turns within the various sub-elements. It was felt, therefore, that these characteristics of circulation would foster different kinds of tests, thereby expanding the concepts of Chapter Two.

II. THE MODEL FOR GENERATION

Alternative forms for the fire station were generated by IMAGE from a limited problem description or "model". The initial model of the problem was limited to only a simplified set of spaces, reduced from the program, and a very minimal set of relationships between those spaces. It was the designer's intention that the model be limited for the initial phase of generation, and elaborated as more was learned from the arrangements generated. In this way, IMAGE could be used by the designer in an heuristic search for an adequate problem description and solution. It was also felt that by
under-constraining the problem, the tests performed could play a greater role in the development of the model.

The seventeen spaces used for the model are listed in Figure 2 on the following page. All the spaces were given the same initial location and the same size (one foot square) to eliminate any form preconceptions which the designer might have had. The relationships specified between the spaces are also shown in Figure 2. These consisted primarily of relative size and proportion along with a few adjacency or proximity requirements. This reflected the architectural program's primary concerns. Each space was scaled to a control space (usually the Apparatus Room) in terms of maximum area and a range of acceptable proportions. The intended effect was to maintain specific areas while allowing the location and proportions to vary as widely as possible. Visual access was required from the Patrol Room to the Apron, the Apparatus Room, and the Restrooms. Of course, non-overlap was specified between all the spaces, since each was to represent an individual room.

The model was specified with all spaces on the same level. This was done because of limitations within IMAGE. The system could have dealt with a multi-floor specification, but much time would have been necessary to improve the system. Since this was not relevant to
the study, and since the architectural program did not demand a two floor scheme (though it was strongly suggested), a single floor model was specified. The primary effect of this was to further limit the number of possible satisfactory alternatives.

The model was additionally removed from reality by the absence of an actual site and its inherent restrictions. The only site characteristic which was built into the model was achieved by fixing the Apron. Since other spaces were related in some way to the Apparatus Room, this had the effect of creating an exclusive "street" on the side of the Apron opposite the Apparatus Room. But no site boundaries, other than the street were specified, or implied.

III. THE DESIGN PROCESS

The fire station study involved five major series of interactions. Each was originated by the generation of a series of arrangements. The arrangements were tested, and on the basis of the tests' results, changes were made to the model and the next sequence was begun.

The designer referred to during this experiment is the author. It would have been possible to use someone else as the designer, thereby avoiding the possibility of a biased analysis of the process. However, it was probable that this alternative methodology would have
merely substituted one person's prejudices for another. It was also possible that many of the designer's insights into his process would have been blurred by their double translation, first by the designer himself and then by the analyst. Due primarily to these two fears, it was decided to condense the two roles of designer and analyst into a single actor and to accept the limitations which that methodology implied.

THE INITIAL GENERATION

Using the generating model as illustrated in Figure 2, IMAGE enlarged all the spaces from their original one square foot area to the size specified. The spaces were also disaggregated from their single locale and repositioned in an effort to satisfy the specified relationships. Figure 3 shows a typical arrangement from this first series of generations.

ERRORS IN THE ARRANGEMENT

There were obvious faults which were common to all the alternatives, and which could be deduced easily from tests made by simple observation. The Apron was too small by one half. It was to have the same dimension on both sides as the Apparatus Room had on its short side. The Officers Quarters (E-CF, L-OF, and W-CF) were moving away from the main cluster of spaces in an unpredictable way. But the most obvious flaw was the fact that the
spaces were badly overlapped. (3.4)

All three of these conditions were so obvious as to virtually test themselves. Only a minimal understanding of the space program and a quick examination of the display was necessary to see the problems.

The errors led to a recheck of the model which was used for the generation. It was found that the non-overlap specifications had been made as intended. Evidently they had to be more highly weighted in order to accomplish their objectives. The Officers Quarters had also been specified as intended, but this allowed them to float. A freedom which was not desired.

The only specification which had been made incorrectly was the size of the Apron. This was a simple oversight and easily rectified.

It would have been irrelevant to test any of the other elements of these arrangements, since the three errors mentioned were so severe as to confuse the rest of the design.

Proximity was specified between the Officers Washroom (W-CP) and the Firemen's Washroom (WASE), and the system was run again.

THE SECOND SET OF ARRANGEMENTS

The best arrangement of the second series of generations is shown in Figure 4a. Two major kinds of
tests were made of this arrangement. First, all the specifications of the model were checked for satisfaction. And second, the circulation necessitated by the arrangement was analysed.

TESTS OF THE MODEL

The model was tested in order to know when it was approaching solution. When nearing solution, it was generally not necessary to continue generating because the trend of the arrangements could be seen. But if the model was not near solution, significantly different arrangements could still be expected.

From tests of these arrangements, it appeared that the generating model had been satisfied with the exception of three conflicts: the Officers Washroom was undersized; and the Mechanical Room was not adjacent to either the Hose Tower or the Locker Room.

Tests of the model were performed by comparing the information contained in the specification matrix with the graphic display of the arrangement. Since all the specifications of the model were simple geometric conditions, visual inspection was usually sufficient to determine their state of satisfaction. The size of the Officers Washroom, for example, was clearly too small. The matrix showed that that space was supposed to be 250 square feet while the Washroom (WASH) was to be 150 s.f. Since the display showed W-OF to be smaller than WASH,
one or perhaps both were incorrect. Comparison of the
WASH to other spaces led to the conclusion that W-OF was
the odd space, probably having been shrunk by IMAGE to
alleviate overlaps.

This kind of multiple comparison is a common form
of testing. Many designers draw design sketches
equately by proportional relationships ('by eye'),
without the aid of a scale. (3,5) It is a simple matter
of checking the consistency between known elements and
concluding that those inconsistencies which are in the
minority are incorrect. This form of testing is given
special note here because of its common use in all forms
of architectural design and because it was used, with few
exceptions, to estimate the state of the generating
model.

TESTS OF CIRCULATION

A brief examination of the arrangement in Figure 4a
will show the reader that the secondary criteria of
circulation were fairly well solved while those relating
to emergency circulation were not. The access between
the various sleeping quarters and their lockers and
washrooms was quite adequate. But unfortunately, it was
impossible to get from any of those dorms to the
Apparatus Room without encountering considerable
congestion and many obstacles. Surely the route from
the Ladder Crew Dorm (L-EM) through the Lockers, the
Washroom, and the Mechanical Room fails to meet the definition of direct circulation. The same was true for nearly all of the major spaces to the Apparatus Room.

As in the tests of the model, most tests of circulation were performed visually. The diagram in Figure 4 illustrates the paths traced mentally from the various spaces to the A-RM. The guidelines for making the paths were 1) not to go outside the arrangement and 2) to go as directly as possible between destinations. The congestion at the Mechanical Room is obvious. And nothing seems sillier than having to pass through a Washroom to get from one major space to another.

CHANGES TO THE MODEL

Proximity was specified between each of the dorms and the A-RM as an indirect representation of the objectives of direct circulation. Alignment was also specified between the Apron and the A-RM.

THE THIRD GENERATION

At this point the designer felt he had developed a fairly complete model of circulation. The computer quickly showed his oversights. Figure 5 shows an alternative which almost completely satisfies the generating model but fails to satisfy the problem.

TESTS OF THE MODEL

As in the last interaction, the latest state of the
specification matrix was compared to the arrangement it generated. The model was virtually solved, except for one anomaly: it was clear that the model was over constrained and inconsistent in its logic relative to the Hose, Storage and Mechanical Rooms. It was seen that the model had declared all three rooms to be adjacent, all to abut the A-RM, and all to be rectangular. That is a geometric impossibility. Of course the proximity relationships were not intended as absolutes. They had been specified primarily to draw the three spaces near, not necessarily touching. However, the discovery that this set of relationships was contradictory caused the designer to re-evaluate his translation of the architectural space program. It was concluded that though the Storage Room was a relatively large space, it was in fact a conglomerate of minor spaces which were more appropriately related to other functions. Because of the gross scale of this model, it could easily be eliminated from the specifications and assumed as dispersed in other rooms.

Moreover, there seemed to be no persuasive argument for having the Mechanical Room near the Hose Tower as opposed to near any other space. And in the absence of such an argument, it seemed unnecessary to influence the arrangement with such a specification. So the proximity between the Hose and Mechanical rooms was eliminated
along with the Storage.

TESTS OF CIRCULATION

The circulation was clearly better than in the previous schemes. Direct access was indeed possible from the major activity areas of the building. But by tracing the paths of hypothetical firemen, it was clear that the objective forbidding cross circulation had failed. Pity the member of the engine crew who, in taking an extra moment to grab a cookey, is run over as he darts from the Dining area to the far side of the A-RM. And it is not too hard to imagine a Buster Keaton as the Engine Officer being trampled in the exit of the Ladder Dorm Cops.

What has happened is fairly common; by concentrating on one problem, the designer failed to consider the contingency of others. The model had been modified to avoid terrors circulation, only to be satisfied with severe cross circulation.

ADDITIONAL SPECIFICATIONS

A satisfactory representation for all the objectives of good circulation had to be developed. It was hypothesized that if the different crews' quarters were on opposite sides of the A-RM, and if the respective officers' quarters were near their own crews, then the two groups would never have to cross each others paths in an emergency. This concept also
necessitated the location of the Recreation and Kitchen-Dining areas on axis with the long dimension of the A-RM, so that men from both crews could get to their trucks without crossing one another's paths. This was tested by a mental check to see if such a specification could result in a satisfactory solution to the circulation. A diagramatic representation of that test can be seen in Figure 6. Since no paths crossed, there was at least a possibility that the additional specifications would solve the problem.

CHANGES TO THE MODEL

As already mentioned, Storage was eliminated and the Mechanical Room - Hose Tower affinity was broken. Besides this, the designer decided to push the Hose nearer the street where he could use it to create a "more interesting" facade. The new specifications for improving circulation were also added, and the model was run again.

THE FOURTH SERIES OF ARRANGEMENTS

Despite the pretest of the circulation criteria, no arrangement could be found which would satisfy the generating model in its latest form. Apparently it was impossible to satisfy all the proximity relationships while maintaining the spaces in their appropriate size and proportion.
An examination of Figure 7 will show that whereas the majority of the proximities are nearly satisfied, certain significant gaps do exist. Moreover, many of the spaces are unreasonably proportioned. Apparently an unreasonable conflict had been created by the number of spaces constrained to occur within the area ringed by the locker and the two dorms. The E-OF and I-CF could have moved outside the ring except for their mutual affinity to the W-OF. The same was true for the WASH and SHWR.

TESTS OF THE MODEL

As in the previous interactions the model matrix was checked for satisfaction, one specification at a time. However, since so many spaces were being squeezed and pushed, it was impossible to be certain of many of the visual tests. For example, it was not clear whether E-OF was undersized in the arrangement or if it was capable of changing proportion in order to meet the Washroom.

Moreover, it was impossible to know how severe the error was. For example, it was obvious that the Recreation Room was undersized, but it was not clear how small it really was. This information could have been determined by using a scale which matched the display to measure the various spaces in question. But unfortunately, the designer had neglected to display a
constant scale symbol with which the measurements would have been improved. This would still have been an arduous process and somewhat inaccurate. Since the information desired was primarily quantitative, and since the computer already possessed that data, it seemed much more useful to develop a routine which would use the actual data on which the computer operated to conduct the tests.

The actual operation of the test routine is described in the next chapter. It enabled the designer to test all the specifications on a space, to find out if they were satisfied or not, and to know how large an error existed. Since the routine showed what specification actually existed, the constant rechecking of the generating model was greatly simplified.

Using this routine it was found that all the spaces at the rear of the Apparatus Room were significantly undersized, out of proportion, or both. The Officer's Dorms, Recreation, and Kitchen-Dining were all too long and narrow. Obviously, all four could not fit within the narrow dimension of the A-RM.

**FINAL CHANGES TO THE MODEL**

The objectives of the architectural program were reviewed and compared to the generating model. Clearly the K-D and REC had to be near the axis of the A-RM since men from both crews would be using the space and
no other location would provide the equal direct egress necessary. On the other hand, the two officers' rooms were related only by proximities to the same space, W-OF, which was now badly stretched. In an effort to resolve the congestion at the rear of the fire house, it was decided to split the W-OF into two equal spaces, one for each of the officers. The proximity between the old W-OF and WASH was not respecified between the two new rooms.

THE FINAL ARRANGEMENT

The arrangement in Figure 8 shows a generation which completely satisfies this model. Tests with the computer routine showed that those specifications which were not satisfied had only minor errors and were well within the acceptable tolerance of the designer. Since the major part of the specification was met, it was decided to look for anomalies outside of the specification.

OTHER OBJECTIVES

The void behind the Kitchen-Dining area was curious and caused questions such as "What could fill it?"; "Could it remain?"; "Could it be a courtyard?"; "Why then doesn't the L-DM have one?". All of which raised the issue of the qualities inside the various living quarters. This made it clear that previous schemes had
not been so generous to the Officers Quarters, which could now have exterior views.

This led in turn to the question, "Why can't the K-D and EEC have an exterior exposure?" The idea of flipping the two spaces with the Locker group was considered. A quick check of the model showed that the proximities to the A-RM would be violated, but the designer questioned the necessity of those relationships in the light of the new possibilities. A check of the architectural program showed no specific requirement of adjacency.

The drawing in Figure 9 shows the designers own arrangement of such a scheme. It is possible in this arrangement to get from the two rear spaces to the A-RM by going through the Locker Room. It could be supposed that this would not be a bad feature since the firemens' boots and coats could be stored there. In fact, if they were stored there, the last computer generated arrangement failed to provide direct paths from the dorms to the lockers to the A-RM. However, the need for such a path was not a known fact - only a supposition. It was equally possible that the coats and boots were kept at the mens' stations on the trucks.

ADDITIONAL INFORMATION

It was clear, then, that additional information was needed in order to continue, since decisions could no
CHAPTER THREE: EXPERIMENT

longer be based on known preferences. Further arrangements would also have to contain more detailed information. For example, knowledge of the placement and size of doors was critical for further testing of circulation. And some concept of the surrounding environment was necessary to evaluate the value of providing the dorms with external exposures.

The study was stopped at this point. The purpose of the study had not been the total solution of the problem, but the exploration of testing. By this point many observations regarding that objective could be made.

IV. OBSERVATIONS

The most obvious lesson of the study was that the designer tested his problem at many different levels. He not only tested the generated arrangements for their satisfaction of the generating model, but for their satisfaction of both the architectural space program and his own objectives as well. He also tested the fit between these different descriptions of the problem to determine how well the generating model represented the space program and to determine how completely the space program represented the many aspects of the problem. This formed a complex network of interdependent tests,
all of which were necessary for the continued improvement of the design.

It appeared that the first arrangements were tested only against the generating model. And since that was so poorly solved, there was little value in testing any other aspects of the problem.

The later generations provided arrangements which largely satisfied the criteria specified in the model while failing to meet the objectives of the space program. In this case, both the arrangement and the model were tested against the larger set of criteria of the space program.
And in the final computer generated arrangement, the form met the specifications of the model and the space program but failed to satisfy the designer's image of the problem.

This is not to infer that a series of tests will always proceed so clearly. The differentiation noted in this experiment was largely due to the computer aided nature of the process. Moreover, as the model and space program were satisfied, the tests of the model, program, and mental image made an untraceable series of jumps, and only the major categories or levels could be identified afterwards. It does seem reasonable to conclude, however, that tests at these different levels are common to all design processes.

Kinds of Tests: State of the Model

By and large, tests of the state of the model were made on the basis of visual inspection and comparison. Since the specifications of the model were all geometric
relationships, they lent themselves to visual analysis. Only when it was clear that large sections of the model were out of order was it necessary to use the computer testing routine.

The visual tests consisted of a set of comparisons between known conditions in which the space that did not appear to meet the pattern was concluded to be in error. This might be characterised as a comparison of the actual form with a mentally expected form in which the measurement of each form was made on the basis of further comparisons (either mental or visual) between one space and several others, where the several others were used as the base or "yardstick".

\[ M(F) = \text{a space compared with others} \]

The test was passed or failed on the basis of the equality of the results of the two measurements - on how well the two forms resembled each other.
The computer aided routine, by contrast, was based on the comparison of numeric values determined by algebraic equations which represented the relationship to be satisfied. And since its base of measurement was absolute, a computer aided test did not need the additional comparisons with which to establish a point of reference. The two types of test procedures established results which varied primarily in accuracy, but did so through entirely different processes.

STATE OF THE OTHER OBJECTIVES

Tests of objectives outside the scope of the model were similar to those performed to determine the state of the model. That is, such tests could all be characterized as comparisons of graphic patterns. This should be clear from the diagram and discussion associated with Figures 4b and 5b.

It should be pointed out, however, that this study was a simple exercise in basic spatial arrangement. It did not get to the level of detail to which most of the architectural program had been written. As a result, it was never possible to test the quality of the flooring or the location and the number of sill cocks. The only kind of tests which were both relevant and possible were
those of basic spatial relationships - all of which could be tested graphically.

While it is obvious that all the specifications in the model and the space program were exhaustively checked, it is unknown how much of the designer's image was ever tested. And it is just as unclear what caused certain aspects of his image to be tested as opposed to others. This type of information could not be determined in this experiment.

**Comparisons Between Problem Descriptions**

Satisfaction of criteria at one level resulted in an escalation of tests to another broader set of objectives. If the arrangement satisfied the model, it was checked against the architectural space program. This in itself is a subtle test of the relevance of one set of objectives to another. However, more obvious comparisons than these were common.

Most objectives, such as direct circulation, are open to some interpretation. By using the computer as a generator, the nature of that interpretation was necessarily very clear; there could be no ambiguity regarding what specification had been used to represent a certain objective. However, this made it both possible and necessary to test how well the
interpretation (in this case the specification) represented its objective. Tests between different problem descriptions were usually made as apriori comparisons of the type of solutions which were acceptable to the different elements: the objective and its representative specification. If it could be seen that the interpretation of an objective would allow solutions which fell outside of the range acceptable to the objective, it did not pass as a reasonable representation. This concept is diagramed in Figure 10.

Circulation provided an excellent example of specifications which failed to adequately represent their objectives. The circulation objectives were interpreted into several different sets of specifications before a satisfactory model was found. During the third generation, the designer considered several possible representations for circulation which he could have specified. Each was analysed to determine if an arrangement might satisfy the specification but not the objectives it represented. It became clear that no single relationship could adequately guarantee the higher level objective of emergency circulation.

Several relationships were finally selected which it was felt would accomplish the objectives desired. These are noted in the discussion of the changes to the model in the third interaction, and the form of their
analysis is illustrated with the diagram in Figure 6.

IMPACT OF THE TESTS

The effects of the various tests were too numerous and varied to draw any general conclusions. Those tests which failed often led to other kinds of tests concerning: which specifications had been made; the adequacy of the specification for its objective; the significance of the objective; the existence of conflicts between different objectives; etc.

On the other hand, successful testing also generated additional tests regarding: the completeness of the model; the satisfaction of the architectural program; the satisfaction of the designer; etc. These all lead to different kinds of actions. At some point, however, one of the following set of tests is made and the process halts: 1) Is the information at hand sufficient to continue? 2) Are the resources sufficient to continue? 3) Is more to be done? If any one is answered negatively, the design is arrested.
FIGURE 2: MATRIX OF GENERATING SPECIFICATIONS

1. APPARATUS RM
   A-RM  2800
   P

2. APRON
   APRN  1600
   VA P

3. PATROL RM
   P-RM  120
   VA P

4. REST RM
   REST  25
   VA P

5. HOSE TOWER
   HOSE  500
   P

6. MECHANICAL
   MECH  545
   P

7. STORAGE RMS
   STOR  205
   P

8. ENGINE DORM
   E-RM  700
   P

9. LADDER DORM
   L-RM  700
   P

10. SHOWER RM
    SHWR  150
    P

11. WASH RM
    WASH  150
    P

12. LOCKERS
    LOCK  650
    P

13. OFFICER RM
    E-OF  315
    P

14. OFFICER RM
    L-OF  315
    P

15. OFFICER WASH
    W-OF  250
    P

16. KIT/DINING
    K-D  320
    P

17. RECREATION
    REC  450
    P

P = PROXIMITY
VA = VISUAL ACCESS
ALL SPACES DECLARED EXCLUSIVE AREAS SHOWN BELOW SPACES' NAMES, ABBREVIATION BENEATH NAME SAME AS SHOWN ON ARRANGEMENTS
FIGURE 3: ARRANGEMENT FROM FIRST GENERATION
FIGURE 4a: ARRANGEMENT FROM SECOND GENERATION

FIGURE 4b: DIAGRAM OF REQUIRED CIRCULATION
FIGURE 5a: ARRANGEMENT FROM THIRD GENERATION

FIGURE 5b: DIAGRAM OF CIRCULATION REQUIRED
FIGURE 6: DIAGRAM OF DESIRED CIRCULATION

ENGINE CREW & OFFICERS

RECREATION KIT/DINING

pumping engine

LADDER CREW & OFFICERS
FIGURE 7: ARRANGEMENT FROM FOURTH GENERATION
FIGURE 2: FINAL COMPUTER GENERATED ARRANGEMENT
Figure 9: Designer's Sketch of Alternative Arrangement
FIGURE 10: CONCEPTUAL DIAGRAM OF SOLUTION SPACES

- AREA OF ACCEPTABLE SOLUTIONS DEFINED BY ARCHITECTURAL PROGRAM
- AREA OF ACCEPTABLE SOLUTIONS DEFINED BY ARCHITECT'S IMAGE OF HIS PROBLEM
- AREA OF SOLUTIONS DEFINED BY MODEL WHICH DOES NOT ADEQUATELY REPRESENT OBJECTIVES OF THE PROBLEM
- AREA OF SOLUTIONS DEFINED BY MODEL WHICH IS AN ADEQUATE REPRESENTATION OF THE OBJECTIVES OF THE PROBLEM
Chapter Four
A COMPUTER TESTING ROUTINE

This chapter describes a computer routine which assists a designer in testing spatial arrangements generated by the IMAGE computer system (See footnote 1.1) The chapter discusses the reasons for developing the routine, how its algorithm is structured, what output is produced by the routine, and how its algorithm might be improved.

I THE PURPOSE OF THE ROUTINE

The testing routine was developed to meet needs which arose during the design experiment discussed in Chapter Three Two of the needs pointed out in that chapter involved the designer's desire to perform accurate tests on the set of specifications which were used by IMAGE to generate spatial arrangements. In testing the generating model, he wanted to know both what specifications were being operated upon (ie what constraints he had specified properly or improperly) and how well those specifications were satisfied by a particular arrangement.

It was possible to obtain this information without
any computer aid, since many of the specifications could be estimated by visual inspection and the number and type of specifications could be examined by making a special search of the IMAGE data structure. However, the visual tests were not uniformly reliable, and the search of the data structure was difficult and time consuming.

A third factor, which was not significant in the design experiment, had to do with analysis and development of IMAGE's generating algorithm. Since that algorithm was still undergoing development, it was advantageous to know what information the algorithm was operating on, and what decisions it was making as a result of the information.

II. THE TEST ALGORITHM

The test routine is a subroutine called from IMAGE's main program. It can access the same data structure upon which IMAGE's generating routine operates. This data structure contains the information concerning the current state of the spaces and the relationships specified between those spaces. The data is organized, as shown in Figure 11, in the form of a semi-lattice or directed graph (4.1).

The designer actuates the test procedure by typing a command to the main IMAGE program which calls the test
subroutine (4.2) A flow chart of the algorithm is shown in Figure 12, and the PL1 program is included in the Appendix for those who would wish to follow the actual commands.

The testing program first asks the designer to type the name of the space he wishes to test. Tests will be made of all relationships specified to the space named by the designer. If the name is typed incorrectly or if the designer names a space which does not exist, the computer will respond with the message "No such space exists", and will ask "Are further tests necessary?" If the designer types "yes", he can try again.

The performance of the actual tests are automatic from this point. The routine searches the data structure from the base point, locating the named test space. It then locates a relationship (also called a constraint) which is specified to that space. From the diagram in Figure 11, if the designer has typed the name "Apron", the routine would search the data structure by tracing each of the branches of the semi-lattice from the base point to the space level of the structure. It would then trace a branch from the APRON "node" to the constraint level, finding FROX1. The other space which related to constraint, is found by tracing the constraints other branch back to the space level of the structure. In the example, the ARM1 would be the
related space.

The type of the constraint and the name of the related space are then typed out for the designer.

The testing routine can access the same subroutines as the main IMAGE program. IMAGE uses a set of subroutines which suggest changes to be made to the arrangement. Each of these subroutines represents one type of constraint which can be specified to a space. Each of these constraint subroutines maintains a general description of the condition which the specification represents. When called by IMAGE, it determines if the two spaces related by the specification satisfy that condition. If they fail, it determines a change which would cause them to meet the condition (4.3).

The testing routine calls the constraint subroutine which matches the specification it has found connected to the test space. In the example, the routine would call the subroutine for proximity. This subroutine checks the arrangement of the APBCN and the A-PM to determine if in fact the two rooms are proximate. If they meet that condition, a "marker" is set that the constraint is satisfied. If they do not, changes are calculated which would modify the test space in order to achieve the condition. The "marker" and the suggested changes are then passed back to the test routine.

If the constraint specification is satisfied, that
is if the "marker" shows that the subroutine has been satisfied, the test routine types out the message "acceptable." Otherwise, the significance with which the condition is violated is calculated and displayed as the "error".

The changes suggested by the constraint subroutine are also displayed on a screen adjacent to the arrangement. From this display, the new configuration of the space can be compared visually with its existing condition as it appears in the arrangement. An example of this display is given in Figure 13.

The test routine continues to search for additional constraints specified to the test space. In the example, it would locate ALIGN and VISACC by tracing out the other branches connected to the test space, APRON.

Once all constraints specified to the space have been tested and the results displayed, the designer is asked "Are further tests necessary?" If the answer is negative, the designer is returned to IMAGE's main program. If he answers "yes", however, he can continue testing his generating model.

III THE OUTPUT

The designer receives a list of constraints specified to the test space; the current state of those
constraints, whether they are satisfied or not; a
relative measure of the significance of their error; and
a display of how the space would be changed by the
constraint subroutines

This information can satisfy a number of questions
the designer might wish to ask. It enables him to make
a quick check of what specifications have been made
properly. Second, he can get a very accurate measurement
of how well a condition is being satisfied. Rather than
relying upon a series of visual comparisons, he can
learn exactly if a geometric condition has been
completely satisfied. Moreover, the error statement
tells him how significantly the condition is violated.
The error is relative, however, and could be improved.
This is discussed later.

Third, the display of the changes suggested by the
constraint show the designer, how the specification
could be satisfied. This goes beyond simple testing,
but can be useful to the design process. For example,
the designer might see that a space is violating several
specifications, but that the changes suggested for one
constraint could solve them all. By changing the space
himself and retesting the model, he can verify his
hypothesis. In this way, he uses the test routine to
make limited experimental changes, without risking the
unknown consequences of using IMAGE's generating
algorithm. He can choose to control the charges directly himself, or allow them to be made under his indirect guidance by the IMAGE system. This substantially broadens IMAGE's capabilities, which were previously limited to automated generation.

Fourth, the display of the suggested changes enables the developers of IMAGE to know both how well the constraint subroutines are functioning, and how well the generating algorithm is incorporating their suggestion. However, this benefit is not directly relevant to this study.

IV. POSSIBLE IMPROVEMENTS

The test routine can be improved in several ways. First, the designer could be allowed to request tests not only in terms of a space, but also in terms of the type of constraint. This would permit him to ask for tests of only the proximity constraints on a given space. This would eliminate tests of the other two constraints on the APBCN in Figure 12.

Alternatively, he could specify his test in terms of a constraint type only. In this case, both PROX1 and PROX2 would be tested. This could be useful in developing new features for the generating algorithm. Those types of constraints which are always violated may need more emphasis. Future improvements to IMAGE may
enable the designer to temporarily suspend all constraints other than a certain type from the generation routine. The ability to test only a certain kind of constraint would be very helpful in this situation.

Of course, both the pair of spaces and the constraint type could be specified together. This would further limit the set of possible tests. (See footnote 3.6)

ADJUSTABLE TOLERANCE

At present the constraint subroutine determines whether or not a condition is satisfied exactly. The magnitude of error is the only estimate of how badly the condition is violated. But since the error is based upon some characteristic of the test space, usually one of its dimensions, it would be possible to permit the designer to specify a tolerance. For example, he could specify that proximity would be satisfied if the two related spaces were within 5\% of the test space's smallest dimension. For those tests which were failed under this tolerance, the error could be displayed either as a percentage of the dimension or as a comparison of two values, the spaces' size and their distance apart.

ANALYSTS OF THE PROBLEM

In many cases, the designer tests an arrangement
not only to know how certain specification are being satisfied, but to learn how well his problem is doing as a whole - to find out which areas of the arrangement are solved and which are not. To address this need, the test routine could be monitored, and operated by another routine which would determine which spaces were satisfied and which ones were not. This routine could permit the designer to ask for the "worst" or "least satisfied" space in the problem. Alternately, he could ask for the constraint or even the type of constraint which was in greatest error. This would in effect permit him to structure information gained from the tests in ways which were most useful to his process.

Naturally this borders on evaluation and could easily be extended into that area by allowing the designer to experiment with different weighting structures for the constraint specifications. In this way, he could easily explore the significance of different value systems on the state of the problem's specification. But this goes well beyond the simple use of testing.

TESTS OUTSIDE THE GENERATING MODEL

At present, only those constraints which operate in the generation routine and which have been specified in the generating model of the problem can be tested. It would be useful, however, to be able to test criteria
other than those which are used for generation. It would be possible, for example, to set up a third (lower) level set of specifications in the data structure which would contain constraints similar to those in the second level but which were not used for generation. (See Figure 14). This would permit the designer to define a set of relationships which were important but which he did not wish to use for generation. For example, he could specify one set of constraints for the generation of a school which represented its educational functions. He could also construct another set of relationships which represented the evening neighborhood use of the building—a set of relationships which would not be important enough to influence directly the arrangement of the spaces. With this double set of relationships the designer could generate forms for the needs of the academic functions, and test them against the other functions which they were to perform.

These are the major kinds of improvements or additions which can be made to this testing routine. There are several areas which lie beyond the scope of the program. These limitations are due to the routine's use of and dependence upon the IMAGE system. It would be advantageous to permit the designer to test criteria other than those of geometry. Color, texture, sound
quality, and occupancy loads are but a few of the factors which a designer might wish to specify and test. At the present time, this is not possible. However, the IMAGE system will be expanded to include data of this type, and additional test routines will be both possible and necessary at that point. For the present, the improvements outlined above are the major changes possible.
FIGURE II: DIAGRAM OF IMAGE DATA STRUCTURE

BASE POINT

SPACES

GENERATING CONSTRAINTS

VISACC  ALIGN  PROXI  PROX2

P-RIM  APP2N  A-RIM
FIGURE 12: FLOW CHART OF TESTING ALGORITHM

MAIN IMAGE PROGRAM

"TYPE NAME OF SPACE TO BE TESTED"

LOCATE SPACE IN DATA STRUCTURE

IS TEST SPACE FOUND? \( N \rightarrow "SPACE DOES NOT EXIST" \)

Y \rightarrow LOCATE CONSTRAINT SPECIFIED TO TEST SPACE

LOCATE OTHER SPACE RELATED BY CONSTRAINT

TYPE OUT: KIND OF CONSTRAINT & NAME OF SPACE

CALL CONSTRAINT SUBROUTINE

IS CONSTRAINT SATISFIED? \( N \rightarrow "ERROR" \)

Y \rightarrow TYPE OUT "ACCEPTABLE"

CALCULATE AND TYPE OUT "ERROR"

DISPLAY SUGGESTED CHANGE

DO OTHER CONSTRAINTS EXIST? \( N \rightarrow "SPACE DOES NOT EXIST" \)

Y \rightarrow ARE FURTHER TESTS NECESSARY? \( N \rightarrow "SPACE DOES NOT EXIST" \)

RETURN TO IMAGE
Arrangement Displayed on Another Screen

Apron As It Exists

Apron As Moved To Align With A-RM

FIGURE 13: TYPICAL DISPLAYS OF TEST INFORMATION
FIGURE 14: DIAGRAM OF POSSIBLE DATA STRUCTURE

BASE POINT

SPACES

GENERATING CONSTRAINTS

NON GENERATING CONSTRAINTS

PROPORTION
APPENDIX I

ARCHITECTURAL SPACE PROGRAM FOR A FIRE STATION

AREAS AND USES

<table>
<thead>
<tr>
<th>Area</th>
<th>Square Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparatus Room</td>
<td>2,300 s.f.</td>
</tr>
<tr>
<td>Patrol Room</td>
<td>120</td>
</tr>
<tr>
<td>W.C.</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,945 s.f.</td>
</tr>
<tr>
<td>Hose Drying Tower</td>
<td>75</td>
</tr>
<tr>
<td>Hose Store Room</td>
<td>75</td>
</tr>
<tr>
<td>Dousing Shower</td>
<td>20</td>
</tr>
<tr>
<td>Clothes Drying Room</td>
<td>130</td>
</tr>
<tr>
<td>Oil Store</td>
<td>30</td>
</tr>
<tr>
<td>Generator</td>
<td>120</td>
</tr>
<tr>
<td>Boiler and Mechanical</td>
<td>400</td>
</tr>
<tr>
<td>Air Compressor</td>
<td>25</td>
</tr>
<tr>
<td><strong>Janitorial and Clean</strong></td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>905 s.f.</td>
</tr>
<tr>
<td>Diesel Pump</td>
<td>50</td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>150</td>
</tr>
<tr>
<td><strong>Total above</strong></td>
<td>2,400 s.f.</td>
</tr>
<tr>
<td>Engine Dormitory</td>
<td>700</td>
</tr>
<tr>
<td>Ladder Dormitory</td>
<td>700</td>
</tr>
<tr>
<td>Firemen's Wash</td>
<td>150</td>
</tr>
<tr>
<td>Firemen's Shower</td>
<td>150</td>
</tr>
<tr>
<td>Linen Closet</td>
<td>50</td>
</tr>
<tr>
<td>Locker Room</td>
<td>650</td>
</tr>
<tr>
<td><strong>Clerical Supplies</strong></td>
<td>25</td>
</tr>
<tr>
<td>Janitorial Cleaning</td>
<td>50</td>
</tr>
<tr>
<td><strong>Household Utility</strong></td>
<td>50</td>
</tr>
<tr>
<td><strong>Total above</strong></td>
<td>135 s.f.</td>
</tr>
<tr>
<td>Engine Officers Room</td>
<td>300</td>
</tr>
<tr>
<td>Ladder Officers Room</td>
<td>300</td>
</tr>
<tr>
<td>Officers Wash</td>
<td>250</td>
</tr>
<tr>
<td><strong>Kitchen Dining</strong></td>
<td>320</td>
</tr>
<tr>
<td>Recreation</td>
<td>430</td>
</tr>
<tr>
<td><strong>Telephone Area</strong></td>
<td>10</td>
</tr>
<tr>
<td><strong>Total above</strong></td>
<td>810 s.f.</td>
</tr>
<tr>
<td><strong>Total Above</strong></td>
<td>4,550</td>
</tr>
<tr>
<td><strong>Total Above</strong></td>
<td>4,185 s.f.</td>
</tr>
</tbody>
</table>
# Fire Station

1. **APPARATUS ROOM**, 2 door, for Engine 33 and Ladder 9. Each bay to be minimum of 1,400 s.f., dimensions 70’ x 20’ as per Firehouse layout criteria’s 1 and 2. 

<table>
<thead>
<tr>
<th>Description</th>
<th>Dimensions</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPARATUS ROOM</td>
<td>70’ x 20’</td>
<td>2,800 square feet</td>
</tr>
</tbody>
</table>

2. **PATROL ROOM**, to contain control console, with seating provision for duty fireman, and commanding functional views of the apparatus room and the firehouse apron and fronting street.

<table>
<thead>
<tr>
<th>Description</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>PATROL ROOM</td>
<td>120 s.f.</td>
</tr>
</tbody>
</table>

3. **LAVATORY and W.C.**, for use by (1) The duty Patrol Room fireman, (2) The public, personnel on ground floor. To be located adjacent to Patrol Room and main entrance to enable use by the duty patrol fireman and use by the public without undue station penetration.

<table>
<thead>
<tr>
<th>Description</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAVATORY and W.C.</td>
<td>25 s.f.</td>
</tr>
</tbody>
</table>

The apparatus room will have particular provision for heating, washing down, draining, air hose, water hose, door control.

4. **HOSE DRYING TOWER**, capable of drying hoses of fifty feet lengths with one fold only. The lower interior walls of the tower to be lined with a material preventing damage to metal hose fittings, the floor of the tower to have water drains. The tower will be so positioned in relation to the pumper engine as to facilitate the handling of hoses from the pumper to the tower.

<table>
<thead>
<tr>
<th>Description</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOSE DRYING TOWER</td>
<td>75 s.f.</td>
</tr>
</tbody>
</table>

5. **HOSE STORE ROOM**, with a minimum capacity of 75 hoses when rolled and stored. Hoses are to be held in troughs of metal pipe design and construction.

<table>
<thead>
<tr>
<th>Description</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOSE STORE ROOM</td>
<td>75 s.f.</td>
</tr>
</tbody>
</table>

6. **DOUSING SHOWER** (with deluge valve) to have two shower heads and a two person capability. Maybe two stalls to open directly onto apparatus room; but does not have to be situated with a particular high speed access or convenience circulation requirement. Water must be heated.

<table>
<thead>
<tr>
<th>Description</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOUSING SHOWER</td>
<td>20 s.f.</td>
</tr>
</tbody>
</table>
1 CLOTHES DRYING ROOM, for the speedy drying of wet firemen's clothing in quantity. Provide for their personnel of three companies plus 25%. Special consideration to be given to the design of clothing racks, which may be of metal tube construction. 180 s.f.

1 OIL STORE, to contain small quantities of oil in metal drums, lockable 30 s.f.

1 GENERATOR ROOM, containing a generator with capacity to carry the full electric load of the fire station in emergency. Generator to have automatic spark, operate on illuminating gas, have provision for automatic testing. Generator to be positioned to permit walk around and to have designed air intake and exhaust 120 s.f.

1 BOILER ROOM and mechanical, to contain heating and ventilating equipment and air compressor 400 s.f.

1 Provision for one electric air compressor providing compressed air to engine and ladder. Air hose should be centrally positioned and service should be from above ceiling 25 s.f.

1 Janitorial and cleaning store, with receptacle of 18" height, shelves and provision for cleaning materials and implements 30 s.f.

1 DORMITORY for ENGINE COMPANY 33 to contain 10 beds of ample size with partitions separating each bed 700 s.f.

1 DORMITORY for LADDER COMPANY 15 as above 700 s.f.

1 FIREFIGHTER'S WASHROOM, containing 3 W.C.'s of ample dimensions and 3 urinals, separate from shower room 150 s.f.

1 FIREFIGHTER'S SHOWER ROOM, containing 4 showers and a drying bench, also containing 6 wash basins equipped with large, good quality mirrors, ample shelving for toilet articles, good lighting and strong towel rails 150 s.f.

Note that total and generous use of the shower room takes place frequently, and that space and abundant hot water are prime requirements, plus exhaust system.
1 LINEN CLOSET................................. 50 s.f.
1 Stationary and clerical SUPPLIES STORE............ 25 s.f.
1 LOCKER ROOM, warm, well-lit and ventilated; containing 1 group of 25 hanging lockers for Engine 33 firemen; 1 group of 25 hanging lockers for Ladder 15 firemen; and one set of 80 bootracks each large enough to hold a "hitch".

The bootracks are not to be more than 3 tiers high.

The lockers are not to be more than 34" wide and 24" deep, and to have dust collection prevention devices on top.

The lockers are not to be less than 24" wide and 24" deep, and to have dust collection prevention devices on top.

There shall be stout, anchored benches between the lockers........................................... 650 s.f.
1 A JANITORIAL CLEANING CLOSET with 18" high receptor. 50 s.f.
1 HOUSEHOLD UTILITY CLEANING CLOSET..................... 50 s.f.
1 OFFICER'S ROOM for ENGINE COMPANY, to contain 2 beds, 4 built-in lockable closets, 1 desk, 1 desk-height, 4 drawer legal size file cabinet, 1 swivel desk chair............ 300 s.f.
1 OFFICER'S ROOM for LADDER COMPANY.
(Provision as for Engine Company)...................... 300 s.f.
1 OFFICER'S WASH and SHOWER ROOM containing 2 wash basins, 1 W.C., 1 urinal, and 1 shower with 2 heads.................................................. 200 s.f.
1 KITCHEN-DININGROOM with provision for gas cooking, and a warming oven, for the storage of dry foods and food under refrigeration, and for cutlery, crockery, etc.

Dining will be off 2 tables, each about 4' x 6' and the room will be so proportioned that the tables will normally be used end to end, ie-

4' x 12'.......................................... 320 s.f.
1 RECREATION ROOM, adjacent to the kitchen-diningroom, and divided from it by a flexible curtain wall to thus enabling joint use of these rooms ........................................ 430 s.f.

There should be provision in or near the above rooms for a cigarette machine, and 2 slot machines dispensing soft drinks and candy.

In this living-dining-recreational area there will be provisional for a wall pay telephone for use by station personnel with a medium of privacy. 10 s.f.

Allow for stair rising to second floor (if any) and to top of hose drying tower. Allow for circulation .......................................................... 700 s.f.
Fire House Criteria (5)  OBSERVATIONS

(1) A two story building lends itself better to rapid alarm-generated circulation than a single story building.

(2) When firemen respond to an alarm signal sounding within the firehouse and response is a reflex action - and partially blind and impetuous. For this reason the emergency routes to the fire vehicles must be as direct as possible and free from obstructions and blind spots.

(3) There will be ample, clear, circulation on the apparatus floor. Equipment will be wall or ceiling hung, walls will be waterproofed as will attendant equipment, the entire capable of hosing down.

(4) Drains in the apparatus room will be ample, contain traps, and be of sufficient strength to support the vehicles.

(5) There must be a heating system in the apparatus room capable of de-icing vehicles and equipment quickly.

(6) The apron in front of the house will have a minimum depth of 30 feet and will fall away from the firehouse. Electric snow melter mats shall be used with an automatic control to prevent icing of ramp.

(7) Vehicle Apparatus Room Doors will have a minimum height of 13 feet and minimum of 13 feet. Doors will have an automatic opening system, but will be capable of manual operation in emergency.

(8) Bumpers will be incorporated as apparatus doors to minimize contact damage. Such bumpers shall be at ground level.

(9) Patrol Room should be in optimin command position, viewing Apron, street and Apparatus Room.

(10) There will be a flagpole.

(11) Landscape and site treatment will be such as to require a minimum of upkeep.

(12) The Gasoline Pump will be card operated and lockable, and enclosed for security - yet naturally vented.
OBSERVATIONS (Cont'd)

(13) A changeover from gasoline to diesel fuel is anticipated. Allow for the future conversion of one full tank to diesel oil, and the installation of a diesel fuel pump.

(14) The Patrol Room must enjoy clear functional views of the apparatus room, the apron, and the immediate highway.

(15) The W.C. on the ground floor is for use by duty personnel in the patrol room. The public may also use this facility. It should be positioned to minimize the consequences of temporary absence of patrol room firemen from the patrol console, and also to minimize penetration of firehouse premises by the public.

(16) Mercury switches with stainless steel wall plates have proved effective and pleasant. Circuit breakers are preferable to fuses.

(17) Intercom and public address systems will be provided throughout the firehouse.

(18) Electric sockets in apparatus room areas shall be waterproofed.

(19) Fire Fighting can be a dirty business for men and machines, and make cleaning an absorbing task. In such areas as is practical, surfaces shall be washable and capable of hosing down. This may consequently require floor drains and slopes to floors in domestic as well as firefighting areas.

(20) Firemen's W.C.'s and wash basins shall be separate from showers.

(21) Janitorial rooms are to be provided with receptors, the front walls of which are to be between 8" to 10" high.

(22) Good quality locks are required throughout and there will be double locking systems on personal lockers.

(23) Personal lockers will have dust-free tops.

(24) The walls of the base portion of the hose drying tower must be surfaced with a cushioning material to prevent damage to metal fittings at hose ends.

(25) Racks for hoses are to be constructed of metal pipe of round cross section. Care will be taken to avoid sharp surfaces or corners on racks which would damage hoses.
(26) Imaginative use of color is expected throughout the firehouse.

(27) There will be a heat actuated alarm system installed in the locker room, linen closet and boiler room.

(28) Ceiling hung light fixtures are preferred, as are flush fitting where practical and possible.

(29) It is common practice for firehouse personnel to maintain one private telephone at private expense. It is commonly a pay station phone. Provision will be made for this phone, and directories, and a minimal writing area or shelf.

(30) All doors on ground floor to be lockable from the outside, (with self-locking latch locks.) but with inside manual opening capability.

(31) There will be a separate water supply line for refilling booster tanks on apparatus on ground floor. Valve and water line shall be 1 1/2 inch diameter equipped with a 1 1/2 inch National Standard Fire Department male thread gated outlet.

(32) Ample sillcocks are a great asset to any fire station if properly located.

(33) Doors on circulation routes should have observation windows of shatter proof glass, and should swing as appropriate.

(34) There will be raised thresholds for the containment of water in hose down areas, where practical.

(35) The consumption of hot food may be delayed by an alarm, consequently a warming oven is required in the kitchen.

(36) While there must be a forced heating device in the hose drying tower, care must be taken to prevent excessive heat capable of damaging hoses.

(37) Hose tower shall be vented to prevent condensation.

(38) Dormitory beds shall be at least 6'6" long and 40" wide.
OBSERVATIONS (Cont'd)

(39) Firemen, in residence under total masculine circumstances, may be observed through firehouse windows naked or half-dressed from time to time. The fenestration design shall minimize this visual possibility.

(40) Kitchen cooker shall be electrical. Range should be commercial heavy duty type.

(41) All exterior pedestrian doors to be self-closing.

(42) The temperature control device for the building heating-cooling system should be automatic, but capable of adjustment by the Fire Officer. The nature and position of the adjustment control should be such as to prevent indiscriminate use by firehouse personnel.

(43) All domestic, office, and hall areas to be air conditioned.

(44) All poles shall be shuttered.

Item 45 Simple because the human numbers are small, the mistake should not be made of assuming that domestic kitchen appliances are suitable for firehouse use. For example, it has been demonstrated that sinks have been installed in the past which were too small to conveniently receive firehouse frying pans. Also, the usual domestic kitchen refrigerator proves to be too small for stations in which there is community food purchases and stock piling and the daily storing of lunches carried in by the firemen.

Item 46 Flooring in a firehouse must be heavy duty. Firemen quite commonly wear boots. Floors should not have to be waxed as firemen in a hurry, moving quickly, and dressing as they travel are in danger of slipping. Additionally, extremely light colored flooring in a firehouse is impractical.

Item 47 There have been previous suggestions concerning the use of color and the creation of an attractive firehouse environment. However, it has been observed in at least two instances that architects in the past have used attractive, heavy duty, water-proof wall papers in the domestic rooms, but have made the mistake of having these papers textured and they have become dirt collectors, not easily washable and requiring scrubbing. The architects are cautioned against this well-intentioned mistake.
Item 48 The walls of the dormitory should be provided with bed lights so that individual firemen may read at night without disturbing the dormitory.

Item 49 Full use should be made of the art of acoustics to provide for maximum quiet in the dormitories.

Item 50 Firemen have to familiarize themselves with the geography of the station's immediate territory. Additionally, they must be familiar with adjacent firehouse territory, which they may visit on their own apparatus in emergencies. For this reason, it is usual to provide wall space for three or more large maps readily and frequently seen by firemen in passing. A position near the Patrol Room is preferred. Drinking fountains should provide cold water.

Item 51 The architect should pay particular attention when designing the Patrol Room to running card index or assignment board. A typical station may have from 150 to 300 items listed and occasionally up to a maximum of 300. The possibility of a rapid use index, circular file, or a display under a glass topped control table have been suggested. Note that individual items are subject to change and consequent removal and replacement. This is worthy of some research and an opportunity for design. Immediate visibility and readability is a prime requirement.

Item 52 Before commencing a firehouse design the architect should spend one full day in a firehouse with Andrew Anderson-Bell of the Public Facilities Department.

Item 53 It is not enough merely to provide automobile parking facilities. Automobiles may be subject to theft or vandalism and security precautions are required.

Item 54 Because of the high visibility required there are often large areas of glass in Patrol Room, and just as often, no special provision for insulation. As a result, Patrol Rooms often become exceedingly hot or exceedingly cold. The architects are cautioned against this mistake.

Item 55 When an alarm sounds the Apparatus Room doors are opened and the entire firehouse staff departs the firehouse on the vehicles. The firehouse doors close automatically and the firehouse lights go out automatically after several minutes, leaving the firehouse unguarded and in darkness. This situation and its frequency should be noted and provided for, particularly in terms of security.
Item 56  When an alarm is sounded at night, the darkened firehouse is illuminated.

Item 57  The impact of the alarm on a sleeping man can have side effects. The Firehouse internal illumination and the alarm bell system should be on separate switches in the Patrol Room so that lights may be switched on one or two seconds before the alarm is sounded.

Item 58  There shall be a provision for low-level lighting in the Apparatus Room at night when the main illumination may normally be switched off.

Item 59  It is not considered an advantage to have a splendid, smooth surface finish under wet conditions. A floor with too rough a surface will hold water by "pocketing" and cannot be satisfactorily squeegee'd.

Item 60  Incredible as it may seem, many instances have been observed in firehouses in which doors did not swing in the direction most appropriate to facilitate rapid movement by firemen responding to an alarm. Also observed were doors hung on the side of the door frame best suitable to impede movement under these circumstances. The designers are warned against this thoughtlessness.

Item 61  In keeping with the principles of maintenance and cleaning, simple roller blinds are preferred to venetian blinds in a firehouse. The designers should be constantly aware that there scarcity of time for cleaning and maintenance throughout the firehouse. The architect should endeavor to assign dust-free kitchens and to incorporate surfaces which lend themselves to cleaning by firemen.
The apparatus should have two thirds of its length clear of the apparatus room before commencing the turn, i.e. minimum 40'.

A turning radius, measured from the outside of the vehicle commencing the turn, of at least 50' shall be allowed.
The design and layout of the Apparatus Room must be based upon this maximum vehicular unit although in practice the space may be occupied by one or more shorter units. A width for circulation is allowed between the apparatus and the long wall, hence the outer bay width minimum of 20'.

It may be advantageous to have one rear entrance if site conditions allow.
APPENDIX II

FL1 PROGRAM FCF COMPUTER AIDED TESTING

TESTER:  FRC (LENGTH, TO, SCALE);

*---------------------------------
DECLARATIONS
*-----------------------*

DCI RET(4) LABEL,
(SXY, IFIRST INITIAL (3)) STATIC,
(IN, PPOD(250,3,6), PTR(1), VISAS(250,7), VPTR) BIN FIXED STATIC,
(SVNAME, IIV, SVN, ISV, OSV, CI, AI, SVVAL, SVCST, SVIL) BIN FIXED STATIC
(SVN2, BIT, IX, IX, OTAB(200), SVUSB, ATAB(400), SVVC) BIN FIXED STATIC
DCL EXFC EXEC RETURNS (ECINTER),
SET (0,27) BIN FIXED BASED(P0),
1 UDATA STATIC,
2 UNAME CHAR(6) VARYING,
2 VARS(9),
2 UV1 BIT(9),
2 MCPE1 BIN FIXED,
2 ECPE2 BIN FIXED, 2 LUF3, 2 LUM4,
GVARS(9),
1 CTRL(3) STATIC,
2 DTYPEX BIN FIXED,
2 DP ECINTER,
2 DL BIN FIXED,
2 MI BIN FIXED,
(I, ISUMTOL, ISUMS, J, N, M, K, II, IC, IN, NNN, XSUM, XSUM) STATIC,
(VNCK, NEWBIT) BIN FIXED STATIC,
1R BIN FIXED INITIAL (1) STATIC,
(IRCT, VNAME, OLDIDPT, OLDID, OLDLOC) BIN FIXED STATIC,
(USE INITIAL (1), CONSTRAINT INITIAL (2),
VALUE INITIAL (3), FRL INITIAL (4)) STATIC BIN FIXED,
INPUT CHAR(1) VARYING,
ID WGNC CHAR(1) VARYING,
IN1 CHAR(4) VARYING,
IN3 CHAR(4) VARYING,
ASTR CHAR(80) VARYING,
QST CHAR(80) VARYING,
SPACE CHAR(10) VARYING,
BRIEF (10) LABEL,
MPROC(50) LABEL,
FRCC EC(50) LABEL,
RETU(4) LABEL,
CUTCH CHAR(8) STATIC,
1 CTAB STATIC,
2 UNAME1 CHAR(8) VARYING,
2 CFTS(6) BIT(9),
2 X,
2 CTCA, 2 CTA2, 2 CDTA3, 2 CDTA4, 2 CDTA5, 2 CDTA6,
2 INCE,
APPENDIX II

(2 CONCT, 2 SEENL, 2 SEE(SE) BIN FIXED,
2 CNAME CCHA(9), 2 DUM1, 2 DUM2,
1 VDATA(6) STATIC,
2 CDATA CCHA(9) VARYING,
2 FEATA(9),
2 UV BIT(9),
2 M1 BIN FIXED,
2 M2 BIN FIXED, 2 DUM5, 2 DUM6,
(VDATAU(6, 9), ANAT(1, 9), CMAT(1, 1), ANS(1, 1), IRANK(9)
BIN FIXED,
SVIDATAU(2, 9), XMAT(9, 1) INITIAL((9)(0, 9))) STATIC;
DECLARE (P, Q, NET1, F(1)) RETURNS (BIT(1)),
ESTART RETURNS (POINTER);

/----------------
INITIALIZATION
----------------*/
INX=0;
INIT: NE8BIT=2;
ITG=0;
IC=9; CLID=9; J=0; CIIC=0; CLCT=0;
INT1=1; INT2=9;

/----------------
GET TEST INFORMATION
---------------------*/
DISPLAY ("TYPE NAME OF SPACE TO EF TESTED") REPLY (IN2);
SPACE = IN211IDWNO;
IGUYID = IDSEM(SPACE);

/----------------
TEST ROUTINE IS AUTOMATIC FROM THIS POINT.
SEARCH DATA STRUCTURE FOR TEST DATA
NOTE: P IS A SPECIAL EFFEGSE LOOP FUNCTION
TO SEARCH THE DATA STRUCTURE.
Q, IDENT, DSDSPL1, IDSEM, AND IDTYEF1
ARE ALSO SPECIAL DATA SEARCH FUNCTIONS.
LOCATE TEST SPACE IN DATA STRUCTURE
----------------*/
P1: IF P(SB, USE) THEN DO WHILE (Q(1B, USE, N));
IDUM=IDENT(SET(USE));
IF (IDENT(SET(USE)) = IGUYID) THEN GO TO SKIP1;
R1: ITG=1;
/*------
GET DATA ON TEST SPACE FROM DATA STRUCTURE
------*/
call DSDSPL1(SET(USE), ADDR(USE)); SVUSE=SET(USE);
CLDC=0; J=1;
DO KKJ=1 TO 9;
XMAT(KKJ,1)=VARS(KKJ);
FNE;
   BYBY:DC I=1 TC 9;IFANK(I)=0;END;
ITJID=IDENT(SET(USE));
DO I=1 TC 9;
GVAR S(I)=VARS(I); END;
/******
NEWPIC BLANKS SCREEN ADJACENT TO DISPLAY OF
ARRANGEMENT BEING TESTED
----------*/
IF INX = 0 THEN DO; CALL NEWPIC(Scale,0.0,0.0);
INX =1; END;
/******
CHNGDSP DISPLAYS TEST SPACE AS IT EXISTS.
-----------*/
CALL CHNGDSP(ITJID,GVAR S(1),GVAR S(2),GVAR S(4),GVAR S(5),UNAME);
CL=1;AL=1;
/******
LOCATE CONSTRAINTS CN SPACE IN DATA STRUCTURE
---------*/
IF P(USE,CONSTRAINT) THEN DO WHILE (Q(1B,CONSTRAINT,N));
CLDTD=IDENT(SET(USE));CLLETSET(USE);
IF OLEC=0 THEN GO TO R2;
N=1;
GO TO CRED;
REPT(1): N=1;
R2:CLDC=1;
/******
GET DATA CN CONSTRAINT FROM DATA STRUCT
----------*/
CALL DSDSPL1(SET(CONSTRAINT),ADDR(UNAME1));
CALL DTYPE1(SET(CONSTRAINT),CTRL(1));
I=0;
/******
LOCATE OTHER SPACE RELATED BY CONSTRAINT
------------*/
IF P(CONSTRAINT,VALUE) THEN DO WHILE ((1D(VALUE,REL,N)):
I=I+1;
CALL DTYPE1(SET(REL),CTRL(I+1));
/******
GET DATA ON OTHER SPACE
----------*/
CALL ESDSPL1(SET(VALUE),ADDR(CDATA(I)));
IF IDENT(SET(VALUE))=CLDI THEN II=I;
ELSE IC=0; SVID=IDENT(SET(VALUE));
SVVAL=SET(VALUE);SVCST=SET(CONSTRAINT);KKH=I;
END;
OUTHERE: FNE; END; ELSE DO;
IF IC=1 THEN DO; OLID=0; IC=J; END; END;
GO TO ICGNE1;
APPENDIX II

END: N=2;
END

ORDER IS THE ROUTINE WHICH CALLS THE CONSTRAINT SUBROUTINES.

GO TO CEDEB;
RETPT (2):
P3: DISPLAY ('ARE FURTHER TESTS NECESSARY') RETLY (IN3);
IF IN3='Y' THEN GO TO INIT;
RETURN;

ORDER: IF IIG=2 THEN DO; DISPLAY('NO SUCH SPACE EXISTS.');
GO TO RETPT (2); END;
DO M=1 TO I;
DO I=1 TO J;
IF A+700=DTYPEX (K+1) THEN DO;
IF K=II THEN VNAME=S;
NC NN=1 TO 9;
VDATAU (M, NN) = DATAU (K, NN);
END; END;
END; END;
K N=DTYPEX (1)-800;
GO TO PROC_NO (NN);
PROC_NO (I) : CALL OVLAP (VNAME, VDATAU, CBITS, VDATA, KEVIT);
DISPLAY ('M-OVERLAP WITH '); CALL FIXLOGO (DATAU (K, NN));
GO TO NAPSET;

SUBROUTINES FOR OTHER POSSIBLE CONSTRAINTS ARE
CALLED IN SIMILAR WAYS, BUT ARE NOT SHOWN HERE.

NAPSET: DO NN=1 TO 9;
AMAT (J, NN) = VDATAU (1, NN);
IF ABS (AMAT (J, NN)) > 1.0E-05 THEN IRANK (NN) = 1;
END;
CHAT (J, 1) = -VDATAU (2, 1);
OUT:

IF A ZERO VNAME IS RETURNED THE TEST HAS
BEEN SATISFIED, OTHERWISE THE ERRR
IS CALLED AND DISPLAYED.

IF VNAME=O THEN EC;
DISPLAY ('IS ACCEPTABLE.');
GO TO RETPT (N); END;
CALL NAPG (AMAT, XMAT, INT1, INT2, INT1, ANS);
ERR=ANS (1, 1)-CHAT (1, 1);
DISPLAY ('IS UNACCEPTABLE. THE ERROR= '||ERR);
DO IGUY=1 TO 5; IF AMAT(1,IGUY)==0 THEN DO;
    AVARY=CMAT(1,1)/AMAT(1,IGUY);
    GVARS(IGUY)=AVARY;
END;
END;

/---------------------
THE CHANCE WHICH WOULD BE MADE BY THE CONSTRAINT
SUBROUTINE IS DISPLAYED.
---------------------*/

CALL CHNGDSP(ITJID,GVARS(1),GVARS(2),GVARS(4),GVARS(5),
               CETA(KNI));
GO TO RETPT(N);
END TESTLAX;
CHAPTER ONE

(1.1) From 1968 until the present, the author was involved in a project whose objective was the development of a computer aid for space arrangement. That project resulted in a system of programs which generated spatial arrangements to satisfy an architectural problem specified by the designer/user.

The system is called IMAGE.

"IMAGE is a network of computer programs which generate three dimensional spatial arrangements to satisfy spatial relationships specified by a designer. A problem specification is composed of two elements: geometric descriptions of the spaces to be configured, and relationships between those spaces which the designer wishes to achieve. Given a problem description, IMAGE generates arrangements until a configuration is achieved which satisfies all specified relationships. If no such configuration is possible, IMAGE produces arrangements which minimize dissatisfaction of the specified relationships.

The dimensions, position and orientation of each space may take on any value in a continuous range and are not confined to discrete intervals. The spaces may overlap or be exclusive according to the relationships specified by the designer, thereby permitting projects to be described in terms of individual rooms or in terms of the activities and functions they serve.

A diverse set of relationships may be used to specify problems. The designer may constrain the size, shape, orientation, and position of any space, and need not limit his specifications to a single type of function, such as trip time or proximity. Different relationships may be combined to represent specific, complex objectives, allowing a designer to tailor his specification to his particular method of design.

It was believed that a computer system which assisted spatial synthesis would enable the designer to explore variations of his image of a problem - to maintain close watch over his objectives - to develop a wide range of alternative schemes, and thereby, to achieve more satisfactory forms."

It was soon realized however, that the ability to generate alternative form solutions to architectural problems was inadequate for designers' needs in at least one major respect: it was incapable of assisting the user in the simple task of testing alternative
arrangements against different criteria. It was in the interest of meeting this need that the study of testing was undertaken. See:  
Johnson, Timothy F., et al.  
IMAGE: An interactive, Graphics-Based Computer System for Multi-Constrained Spatial Synthesis (Cambridge: MIT Dept. of Architecture, 197)

(1.2) See the discussion of "City Design", "City Designing", and "Functional Analysis of City Design" in:  
Porter, William L  
The Development of Discourse: A Language for Computer Assisted City Design,  

(1.3) An elaborate presentation of the synoptic approach to problem solving and its weaknesses as compared to heuristic approaches provides the basic content of:  
Braybrooke, David and Lindblom, Charles  
A Strategy of Decision  

CHAPTER TWO
(2.1) Several well known volumes exist, the best known of which is Ramsey and Sleepers, Graphic Standards.

(2.2) This Phenomenon was observed by Dr. Robert Weiss during a case study of the Seattle World Fair done for IBM. Other observations are reported in:  
Weiss, Robert S. and Boutourline, Serge  
Fairs, Pavilions, Exhibits, and Their Audiences  
Unpublished IBM Report, 1962

CHAPTER THREE
(3.1) The program was made available for the study by Ashley, Myer, Smith, Architects, Cambridge. It had been used by that office for the remodelling of an existing fire house, the Back Bay Station, and had been provided for the architectural remodelling by the Public Facilities Department of the City of Boston. The purpose of the remodelling was to bring the physical condition of the fire house, built near the turn of the century, up to the quality of recently constructed stations. The program, therefore, was not significantly
changed from those used for new construction.

(3.2) During visits to the fire house, the architects found that security of possessions was very important to the firemen. Evidently, snooping and pilferage were not uncommon among the men on duty. Several men indicated a desire for lockable closets and storage areas which could be easily and continuously observed and guarded. Consistent to most architectural programs, no mention of needs of this kind was made.

(3.3) To a large extent, the selection of the fire station was made on the commendation by the designers at the architects office that this program was far and away the most complete that had been used in the office.

(3.4) Whereas IMAGE attempts to alleviate all errors, at any point during the generation process, a large portion of the model may be in error.

(3.5) A design instructor at the University of Arizona once failed to attend a student party on the grounds that the map to the party had been drawn with "utter disregard for relative distances". He had deduced from other relationships on the map that the party was about a mile from a locating intersection, when in fact it was three miles. Having driven the mile and not locating the house, he returned home in confusion.

(3.6) An excellent discussion of set theory, the algebra of events, is given in the first chapter of:

Drake, Alvin W
Fundamentals of Applied Probability Theory

CHAPTER FOUR

(4.1) For a more detailed discussion of this data structure system see the appendix of:

or
Crick, M P Iorie, R.A. Mosher, E J. and Symonds, A J
A Data System for Interactive Applications
(Cambridge, IBM Report 321-2658, 1971)

(4.2) IMAGE operates on an IBM 360/67 computer using the CP/CMS time sharing system. The user communicates with the system by a typewriter-like console. His typed commands, as well as typed and 2 dimensional graphic responses, are displayed on a small optical screen,
similar to a television screen

(4.3) For a more elaborate discussion of the various constraints possible within IMAGE, the conditions they seek to satisfy, and the way in which IMAGE uses them during generation, see Chapter 2: The IMAGE System, in: Timothy Johnson, et al, Op Cit, 1970
Alexander, Christopher
Notes on the Synthesis of Form

Braybrooke, David and Lindblom, Charles
A Strategy of Decision
New York: Free Press, 1963

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