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Author(s): Allen Bernholtz and Edward Bierstone
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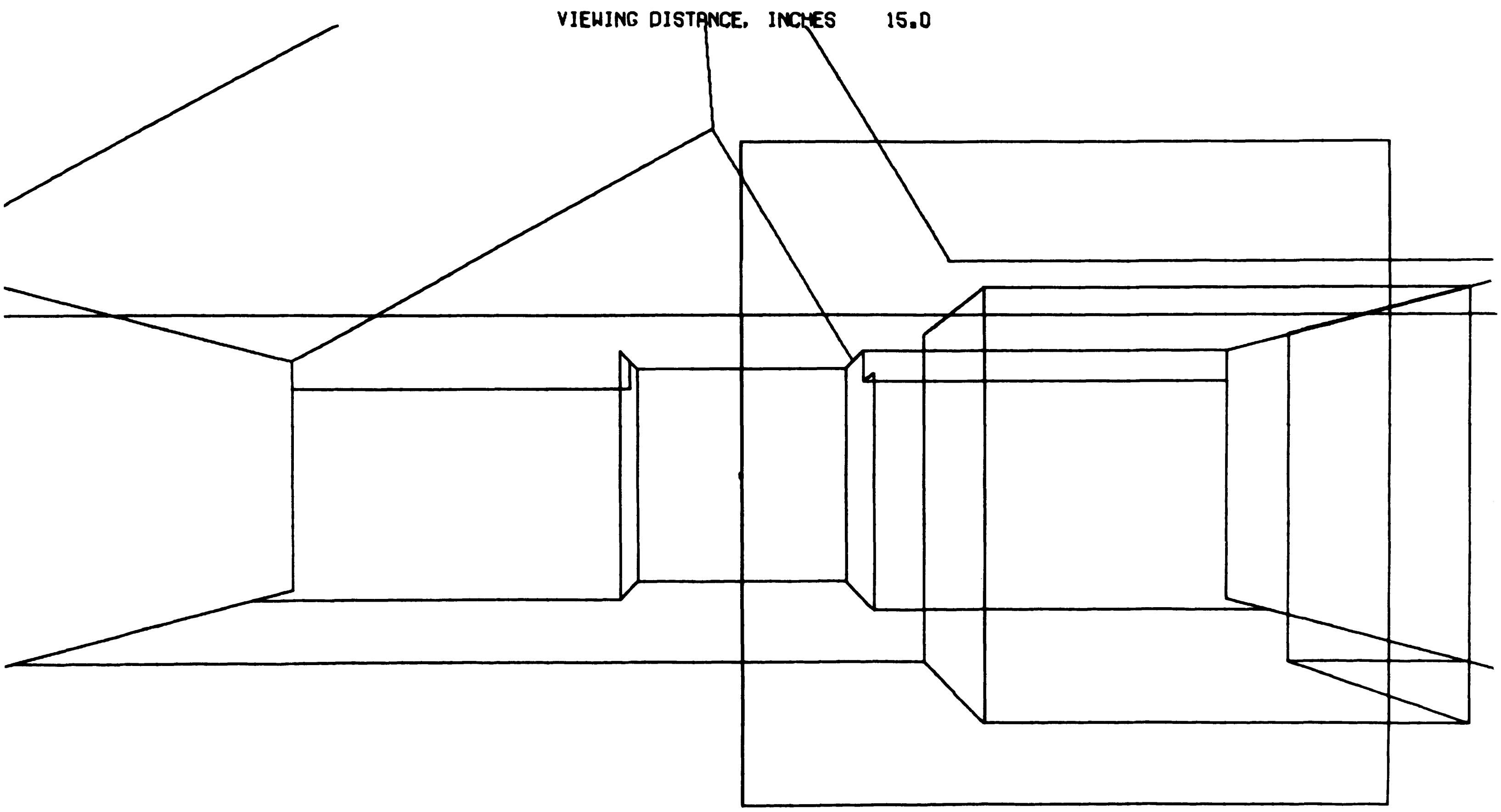
One of a series of computer plots showing the inside of a small studio. Perspective computer programs driving the plotter allow the architect to pretest the design from all points of view and different distances.



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COMPUTER-AUGMENTED DESIGN

A Case History in Architecture
by Allen Bernholtz and Edward Bierstone

Allen Bernholtz is assistant professor of Architecture and Computer Technology in the department of Architecture, Graduate School of Design, Harvard University. Formerly assistant professor of architecture at the University of Toronto, Canada, he obtained a grant from the National Research Council (Canada) for research on computers and architecture. Edward Bierstone, who collaborated with Mr. Bernholtz on this computer project, is a student of architecture at the University of Toronto.

In any design problem, certain requirements have to be met by the designer or architect. The interaction between the individual requirements makes it difficult to fulfill them all. When these requirements are few, as in the design of a simple product, the solution remains readily within the reach of the designer's immediate ability. But how does he proceed when confronted with a complex problem such as the design and location of highways, the architectural and organizational problems of hospitals or even the total environment for millions of people?

The complexity of such problems is so great that the designer and the architect will be unable to arrive at correct solutions unless a new way is found to structure the problem by breaking it down into smaller problems.

Christopher Alexander's method of the "hierarchical decomposition" and the computer program devised by him and Prof. Manheim break a design problem down into subsets. This method, here applied to the architectural project of a medium-size house, can also be used in the design of highways and, perhaps, even in the design of a whole city.

The complexity of today's design problems demands a revision of the processes of both analyzing the problem and synthesizing its solution. In the use of the computer as an aid to design lies the potential for such a revision and, therefore, the potential for the production of forms of consistent aesthetic and functional clarity.

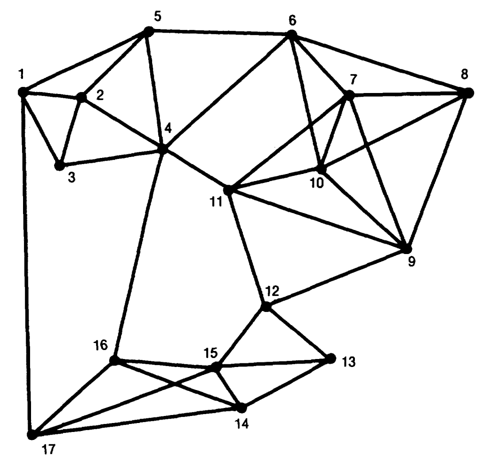
Using the IBM 7094 Computer at the University of Toronto's Institute of Computer Science, experiments have been undertaken with the application of the computer to the analysis of a design problem based on the inherent structure of the problem, and the formulation of a direction of attack for the synthesis of the form. An actual house design furnished a test case for the research and is used here as an example.[1]

COMPUTER-GENERATED FORMALIZATION OF THE DESIGN PROBLEM

Because of the great number of requirements to be simultaneously considered in an architectural design problem, the odds are heavily against the designer producing a solution which both satisfies the requirements, and especially their interactions, and at the same time achieves clarity of form. The designer usually attempts to structure the problem by verbally grouping these factors, or requirements, into "acoustics," "zoning," "circulation," and so on, and proceeds then to design by considering each *group* of requirements more or less independently.

But, as Christopher Alexander has explained in his book, *Notes on the Synthesis of Form,*[2] this grouping of requirements by verbal concepts is irrelevant to the structure of the specific problem and introduces only further error into the already overly-complex design program. Alexander therefore proposed to describe the problem by a set of "misfit" factors, that is, by ways in which a form can "go wrong" and by a set of interactions between the misfits.

In the design problem discussed here, as in almost any design problem, it is not exactly the requirements or misfit factors that make up the project, although the designer has to find a form that finally reflects these requirements. After establishing all the requirements which have any influence or relation to the physical shape of the building, in the present case, 72 requirements, the problem is then to determine the links that connect them, to find the ways in which they interact. (Two misfits interact if the decisions the designer makes about the form to satisfy one, will affect the decisions he makes when considering the other.) This set of requirements and the set of links can be demonstrated by a linear graph where each requirement is represented by a point, and each interaction between requirements is represented with a link between the corresponding pair of points.



Linear graph for a design problem involving 17 requirements. Each numbered dot represents a need or requirement and each line or edge connecting these numbered dots indicates an interaction.

Such a graph presents us with a structural description of the functional total. This description then can be mathematically interpreted to suggest criteria for subdivision of the problem into subsystems, that is, functional units or components of the whole. Using a measure of independence to evaluate each possible way of subdividing the system, the designer then divides it into subsystems that are as independent as possible.

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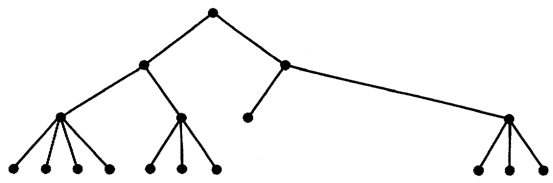
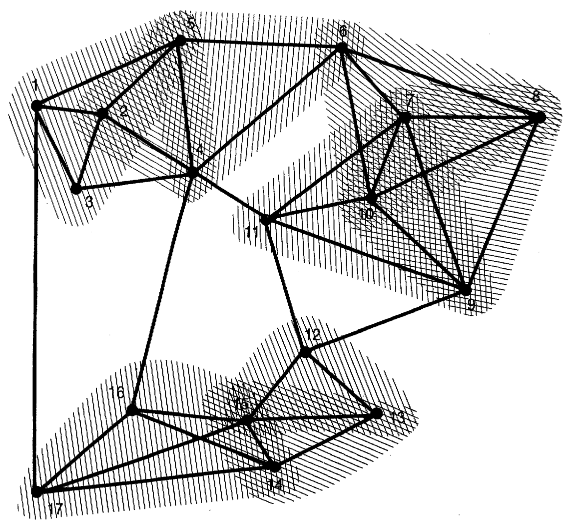
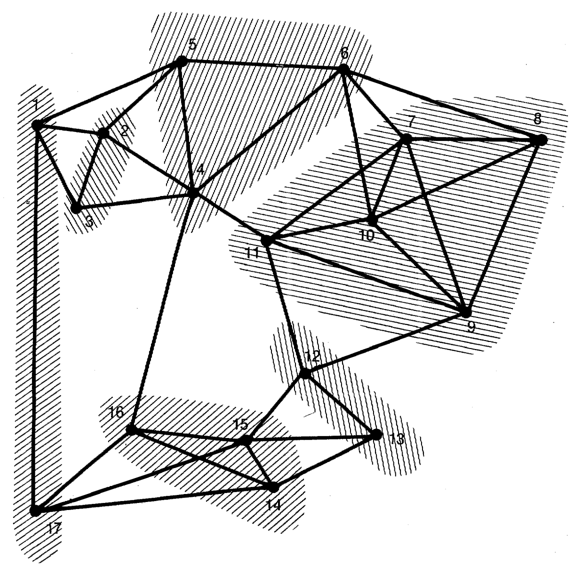


A computer program is used to produce a hierarchy by dividing the problem, in this example consisting of 17 requirements, into its two most independent parts, and continuing the process until a series of independent subsystems are achieved.



Graph showing the 17 requirements decomposed by a specific computer program into subsystems. Each subsystem consists of a minimum of three requirements, with each requirement linked to every other one within the subsystem.



A specific computer program is used to yield disjoint subsets of a problem consisting of 17 requirements. In contrast to the example above, this program does not produce subsets which overlap.

HIERARCHICAL DECOMPOSITION

Together with Marvin L. Manheim, Christopher Alexander developed in HIDECS 2 a computer program which divides such a system into its two most independent parts, and then repeats the process, operating on each of the subsets resulting from the previous operations, until complete subsystems (subsets with every pair of points linked) are produced.[3] This computer program yields a tree of hierarchy as the design program which we can solve by first finding solutions to the subproblems at the lowest level of the tree, and then proceeding to combine solutions, finally, into the complete form, in the order defined by the hierarchy. This program, however, has two faults: first, the decomposition of the system in binary steps results in misfit factors being considered only in the context of an immediately preceding subsystem but not in the context of the system as a whole; and second, the subsets of elements generated have no elements in common, although the most natural subsystems of a system may contain common elements.

To correct these weaknesses, Alexander developed four new programs under the title HIDECS 3. The programs, called BLDUP, STABL, SIMPX, and EQCLA, each decompose the set of interactions between the requirements in a single step, i.e. not into a hierarchy of subsystems.[4] In addition, two of them, SIMPX and EQCLA, generate subsystems which may overlap. (The names of these four computer programs conform to the custom in computer jargon of identifying these specific programs by relating the name of the program to the subject of the program — in this case EQCLA is a convenient name because it determines EQuivalent CLAsses of triangles.)

These programs, however, introduced a new problem: decomposition in a single step eliminates hierarchical ordering which is necessary in the design process because it allows for a design program starting with finding solutions for subsets beginning on the lowest level.

HIDECS 2, then, by decomposing the system in a series of binary steps yielding a hierarchy, sacrifices the unity of the system, while HIDECS 3, by decomposition in a single step, preserves the unity at the expense of the hierarchy. It became apparent that it was necessary to begin with a one-step decomposition, and then employ a procedure to recombine the resulting subsystems into a hierarchy.

HIERARCHICAL RECOMPOSITION

SIMPX, one of the HIDECS 3 computer programs, which generates complete subgraphs of a linear graph as subsystems, was used to yield the initial decomposition for this particular test problem. Each element in the subset is joined to every other element in that subset.

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Since many of the subsystems generated by SIMPX contain common requirements, and since the aim of the computer decomposition is the production of subsets which the designer may solve independently, a natural criterion for the recomposition of these subsystems into a "tree" capable of being used as a design program is the combination of subsystems containing common requirements. The HIDECS 3 program BLDUP can be used for this purpose because it divides the elements into disjoint subsets (having no elements in common), so that in a decomposition the subsets do not overlap.

The subsystems yielded by the SIMPX program, that is the decomposition method which yields overlapping subsystems, are numbered and considered as single elements; two such elements are considered linked if they contain one or more common misfit factors. This information, then, defines a linear graph and its associated matrix of linked elements. BLDUP, the method of decomposition which yields disjointed subsets, is then used to group the initial subsystems obtained by SIMPX. The process is performed twice more, the first time considering two elements as linked if they contain two or more misfit factors, and the second time considering two elements as linked if they contain three or more common misfit factors.* Of the three outputs, the one which yields the best composition of subsystems, from the point of view of the number of subproblems that may be conveniently combined in a single step, is used for the second lowest level of the hierarchy.

Now, considering the disjointed subsystems as elements, and defining links as above, BLDUP is again run three times, and one of the outputs is chosen for the third level of the hierarchy. The process is continually repeated until the program yields a number of subsystems sufficiently small to be combined in a single step, into the entire system. A hierarchy defining the order of recomposition of the subproblems is thus produced.

THE DESIGN OF A HOUSE AS A SAMPLE PROBLEM

The following is a list of misfit factors which are related to or influence the architectural form of this particular house.

Since Fitness of Form, "the relation of mutual adaptability of form and requirement," is better noticed or described when it is negative or absent, the requirements for this design problem are here introduced as negative factors. This in turn means that good adaptability of form to requirement is achieved by neutralizing the discrepancies or forces which cause misfit in the design process.

*The number of common elements in a subsystem on a particular level determines the numbers likely to be used to define interactions between subsystems. The definition of interactions for a level containing subsystems with a great many common elements may be based on a number of common elements greater than three.

MISFIT FACTORS

1. Inadequate protection for cars.
2. Large area to be snow-shovelled in winter.
3. No provision for hobbies.
4. Siting of dwelling hinders development of vegetable, flower gardens.
5. Eastern Canadian woods little used in design and furnishing.
6. Habitable spaces not naturally well-ventilated.
7. No provision for reception of delivery, mail, parcels.
8. No exterior space for rest.
9. No exterior conversation space.
10. No exterior space for children's play.
11. No protection during arrival and entry.
12. No meeting space for arrivals.
13. No provision for storage of outdoor clothes.
14. No protection from dust and dirt.
15. No protection from animals, insects, vermin.
16. No protection from human intruders.
17. No separation of children from vehicles.
18. Poor fire protection.
19. Transmission of exterior noises.
20. Transmission of interior noises to quiet areas.
21. Difficult emergency access.
22. Difficult emergency escape.
23. Access from car to dwelling involves long distance.
24. Inconvenient system of garbage disposal.
25. Inadequate provision for garbage collection.
26. Inadequate food storage.
27. Food processing inconvenient.
28. Food conservation inadequately provided for.
29. Inadequate storage for culinary and eating equipment.
30. Poor provision for cleaning of culinary and eating equipment.
31. Inadequate eating facilities.
32. Poor accessibility to public utilities.
33. Poor sun control.
34. Dwelling enclosure vulnerable to rain.
35. Poor wind control.
36. Little resistance to changes in temperature, humidity.
37. Inaccessibility to top of dwelling.
38. Heating difficult to control and maintain.
39. Inadequate water-heating system.

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40. Inconvenience in reaching telephone.
41. Poor provision for radio, recordings.
42. Poor provision for television.
43. Inadequate facilities for washing of laundry.
44. Inadequate facilities for drying of laundry.
45. Inadequate facilities for ironing of laundry.
46. Inadequate or inconvenient facilities for washing.
47. Inadequate or inconvenient facilities for bathing and showering.
48. Inadequate or inconvenient facilities for elimination of excreta.
49. No provision for storage of medicinal supplies.
50. No provision for storage of toiletries.
51. Inadequate facilities for personal care.
52. Poor facilities for solitude for members of family.
53. Poor facilities for rest, sleep for members of family.
54. Poor love-making facilities for parents.
55. Inadequate provision for storage of personal possessions.
56. Poor facilities for dressing and undressing.
57. Poor provision for storage of clean clothing.
58. Poor provision for storage of clothing in use.
59. Poor provision for storage of clothing to be washed.
60. Poor provision for storage of linen.
61. Inadequate facilities for studying and writing.
62. Inadequate facilities for reading.
63. Poor provision for storage of gardening and exterior maintenance equipment.
64. No separation of pets from vehicles.
65. No provision for storage of domestic cleaning equipment.
66. No provision for storage of domestic repair equipment.
67. No provision for storage of sports equipment.
68. No provision for general storage, luggage, etc.
69. No provision for storage of clothing in seasonal use.
70. Inadequate facilities for family activities.
71. Inadequate facilities for activity with guests.
72. Inadequate facilities for repair of clothing.

SET OF LINKS BETWEEN MISFIT FACTORS

Each of the 72 misfit factors connects or interacts with one or more of the other factors. It is essential to find and identify those links which most definitely relate to the structure of the problem. The following links have been determined and used for this test problem:

Misfit factor 1, *Inadequate protection for cars,* is connected to:

2 (Large area to be snow-shovelled in winter)
11 (No protection during arrival and entry)
17 (No separation of children from vehicles)
19 (Transmission of exterior noises)
23 (Access from car to dwelling involves long distance)
63 (Poor provision for storage of gardening and exterior maintenance equipment)
64 (No separation of pets from vehicles)
67 (No provision for storage of sports equipment)

Misfit factor 2, *Large area to be snow-shovelled in winter,* is connected to:

1 (Inadequate protection for cars)
7 (No provision for reception of delivery, mail, parcels)
11 (No protection during arrival and entry)
21 (Difficult emergency access)
23 (Access from car to dwelling involves long distance)
25 (Inadequate provision for garbage collection)
37 (Inaccessibility to top of dwelling)
63 (Poor provision for storage of gardening and exterior maintenance equipment)

Misfit factor 3, *No provision for hobbies,* is connected to:

6 (Habitable spaces not naturally well-ventilated)
7 (No provision for reception of delivery, mail, parcels)
8 (No exterior space for rest)
14 (No protection from dust and dirt)
18 (Poor fire protection)
20 (Transmission of interior noises to quiet areas)
24 (Inconvenient system of garbage disposal)
40 (Inconvenience in reaching telephone)
44 (Inadequate facilities for drying of laundry)
46 (Inadequate or inconvenient facilities for washing)
53 (Poor facilities for rest, sleep for members of family)
61 (Inadequate facilities for studying and writing)
62 (Inadequate facilities for reading)
66 (No provision for storage of domestic repair equipment)

Misfit factor 4, *Siting of dwelling hinders development of vegetable, flower gardens,* is connected to:

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8 (No exterior space for rest)
9 (No exterior conversation space)
10 (No exterior space for children's play)
15 (No protection from animals, insects, vermin)
33 (Poor sun control)
35 (Poor wind control)
40 (Inconvenience in reaching telephone)
46 (Inadequate or inconvenient facilities for washing)
63 (Poor provision for storage of gardening and exterior maintenance equipment)

Misfit factor 5, *Eastern Canadian woods little used in design and furnishing,* is connected to:
6 (Habitable spaces not naturally well-ventilated)
19 (Transmission of exterior noises)
20 (Transmission of interior noises to quiet areas)
33 (Sun uncontrolled)
34 (Dwelling enclosure vulnerable to rain)
35 (Wind cannot be controlled)
36 (Little resistance to changes in temperature, humidity)
38 (Heating difficult to control and maintain)

Misfit factor 6, *Habitable spaces not naturally well-ventilated,* is connected to:
3 (No provision for hobbies)
5 (Eastern Canadian woods little used in design and furnishing)
14 (No protection from dust and dirt)
15 (No protection from animals, insects, vermin)
16 (No protection from human intruders)
19 (Transmission of exterior noises)
20 (Transmission of interior noises to quiet areas)
24 (Inconvenient system of garbage disposal)
27 (Food processing inconvenient)
33 (Sun uncontrolled)
34 (Dwelling enclosure vulnerable to rain)
35 (Wind cannot be controlled)
36 (Little resistance to changes in temperature, humidity)
38 (Heating difficult to control and maintain)
44 (Inadequate facilities for drying of laundry)
48 (Inadequate or inconvenient facilities for elimination of excreta)

Misfit factor 7, *No provision for reception of delivery, mail, parcels,* is connected to:
2 (Large area to be snow-shovelled in winter)
3 (No provision for hobbies)
11 (No protection during arrival and entry)
12 (No meeting space for arrivals)
14 (No protection from dust and dirt)
15 (No protection from animals, insects, vermin)
16 (No protection from human intruders)
17 (No separation of children from vehicles)
19 (Transmission of exterior noises)
26 (Inadequate food storage)
32 (Poor accessibility to public utilities)
34 (Dwelling enclosure vulnerable to rain)
35 (Wind cannot be controlled)
64 (No separation of pets from vehicles)
68 (No provision for general storage, luggage, etc.)

The rest of the interactions between the misfit factors are listed numerically only:

Misfit factor 8 is connected to:
3, 4, 9, 10, 13, 14, 15, 16, 19, 52, 53, 54, 61, 62.
Misfit factor 9 is connected to:
4, 8, 10, 13, 14, 15, 16, 19, 40, 53, 61, 62, 70, 71.
Misfit factor 10 is connected to:
4, 8, 9, 13, 14, 15, 16, 17, 19, 27, 46, 53, 61, 62, 67.
Misfit factor 11 is connected to:
1, 2, 7, 12, 14, 15, 19, 21, 22, 34, 35.
Misfit factor 12 is connected to:
7, 11, 13, 14, 15, 16, 19, 46, 48.
Misfit factor 13 is connected to:
8, 9, 10, 12, 46, 71.
Misfit factor 14 is connected to:
3, 6, 7, 8, 9, 10, 11, 12, 15, 16, 19, 24, 25, 34, 35, 44.
Misfit factor 15 is connected to:
4, 6, 7, 8, 9, 10, 11, 12, 14, 16, 19, 24, 25, 26, 28, 34, 35, 44, 57, 60, 69.
Misfit factor 16 is connected to:
6, 7, 8, 9, 10, 12, 14, 15, 19, 21, 34, 35.
Misfit factor 17 is connected to:
1, 7, 10, 23, 64.
Misfit factor 18 is connected to:
3, 20, 36, 38, 39.
Misfit factor 19 is connected to:
1, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 23, 34, 35, 36.
Misfit factor 20 is connected to:
3, 5, 6, 18, 38, 40, 41, 42, 72.
Misfit factor 21 is connected to:
2, 11, 16, 22.
Misfit factor 22 is connected to:
11, 21.
Misfit factor 23 is connected to:
1, 2, 17, 19, 64.
Misfit factor 24 is connected to:
3, 6, 14, 15, 25, 27, 30, 46, 63.
Misfit factor 25 is connected to:
2, 14, 15, 24.
Misfit factor 26 is connected to:
7, 15, 27, 28, 29, 31.

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Misfit factor 27 is connected to:
6, 10, 24, 26, 28, 29, 30, 31, 40, 46, 49, 65.

Misfit factor 28 is connected to:
15, 26, 27, 29, 31.

Misfit factor 29 is connected to:
26, 27, 28, 30, 31.

Misfit factor 30 is connected to:
24, 27, 29, 31, 40, 46, 65.

Misfit factor 31 is connected to:
26, 27, 28, 29, 30, 40, 46, 70, 71.

Misfit factor 32 is connected to:
7, 38, 63.

Misfit factor 33 is connected to:
4, 5, 6, 36.

Misfit factor 34 is connected to:
5, 6, 7, 11, 14, 15, 16, 19, 35, 36.

Misfit factor 35 is connected to:
4, 5, 6, 7, 11, 14, 15, 16, 19, 34, 36.

Misfit factor 36 is connected to:
5, 6, 18, 19, 33, 34, 35, 38.

Misfit factor 37 is connected to:
2, 63.

Misfit factor 38 is connected to:
5, 6, 18, 20, 32, 36, 39.

Misfit factor 39 is connected to:
18, 38, 43, 46, 47.

Misfit factor 40 is connected to:
3, 4, 9, 20, 27, 30, 31, 41, 42, 43, 45, 61, 62, 70, 71.

Misfit factor 41 is connected to:
20, 40, 42, 70, 71.

Misfit factor 42 is connected to:
20, 40, 41, 70, 71.

Misfit factor 43 is connected to:
39, 40, 44, 46, 59.

Misfit factor 44 is connected to:
3, 6, 14, 15, 43, 45, 57.

Misfit factor 45 is connected to:
40, 44, 46, 57, 60, 69, 72.

Misfit factor 46 is connected to:
3, 4, 10, 12, 13, 24, 27, 30, 31, 39, 43, 45, 47, 48, 49, 50, 51, 52, 53, 54, 56, 60, 63.

Misfit factor 47 is connected to:
39, 46, 48, 50, 51, 53, 54, 56, 57, 58, 60.

Misfit factor 48 is connected to:
6, 46, 47, 50, 52, 53, 54, 70, 71.

Misfit factor 49 is connected to:
27, 46, 50, 51.

Misfit factor 50 is connected to:
46, 47, 48, 49, 51, 56.

Misfit factor 51 is connected to:
46, 47, 49, 50, 55, 56.

Misfit factor 52 is connected to:
8, 46, 48, 53, 54, 61, 62, 70, 71.

Misfit factor 53 is connected to:
3, 8, 9, 10, 46, 47, 48, 52, 54, 56, 60, 70, 71.

Misfit factor 54 is connected to:
8, 46, 47, 48, 52, 53, 56, 70, 71.

Misfit factor 55 is connected to:
51, 56.

Misfit factor 56 is connected to:
46, 47, 50, 51, 53, 54, 55, 57, 58, 59, 68.

Misfit factor 57 is connected to:
15, 44, 45, 47, 56, 58, 59, 60, 69.

Misfit factor 58 is connected to:
47, 56, 57, 59.

Misfit factor 59 is connected to:
43, 56, 57, 58.

Misfit factor 60 is connected to:
15, 45, 46, 47, 53, 57.

Misfit factor 61 is connected to:
3, 8, 9, 10, 40, 52, 62, 70, 71.

Misfit factor 62 is connected to:
3, 8, 9, 10, 40, 52, 61, 70, 71.

Misfit factor 63 is connected to:
1, 2, 4, 24, 32, 37, 46, 66, 67.

Misfit factor 64 is connected to:
1, 7, 17, 23.

Misfit factor 65 is connected to:
27, 30, 66.

Misfit factor 66 is connected to:
3, 63, 65, 72.

Misfit factor 67 is connected to:
1, 10, 63, 68.

Misfit factor 68 is connected to:
7, 12, 56, 67, 69.

Misfit factor 69 is connected to:
15, 45, 57, 68, 72.

Misfit factor 70 is connected to:
9, 31, 40, 41, 42, 48, 52, 53, 54, 61, 62, 71.

Misfit factor 71 is connected to:
9, 13, 31, 40, 41, 42, 48, 52, 53, 54, 61, 62, 70.

Misfit factor 72 is connected to:
20, 45, 66, 69.

The above links were determined directly as the data cards were punched. Each link decision was made twice, and the computer was programmed to eliminate those links defined only once in the process, to produce a symmetric matrix. In spite of a rapid definition of this data, however, an examination of the final hierarchy produced testified to the logic of the list of requirements and their estimated interaction.

Data based on subsystems having two or more common elements were used for the lowest level of the hierarchy while data based on subsystems having three or more common elements were used for the second and third levels. Data based on subsystems having two or more common elements were used for the fourth level, and finally, data based on subsystems having one or more common elements were used for the fifth level, which is composed of two large subsystems of the system of misfits and links.

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Level by level recomposition into a hierarchy of the subsets representing the architectural problem of a house design. This hierarchy constitutes the design program of the architect.

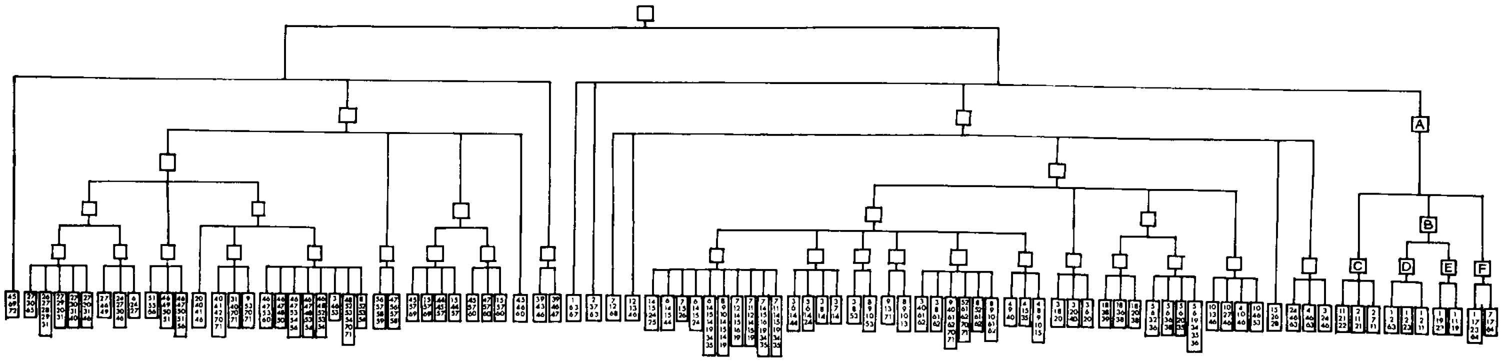
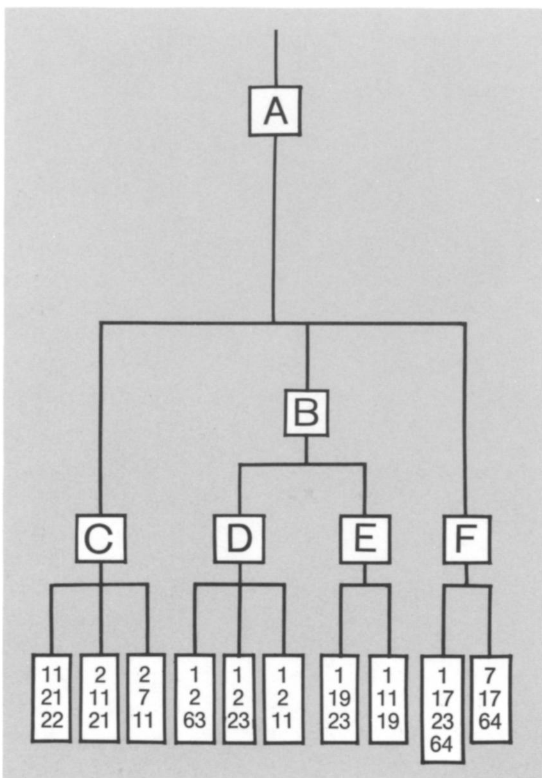


Diagram showing Subsystem A (including subsets B, C, D, E and F) of the above hierarchy. Subsystem A represents the garage and entrance area (Misfit factors 1, 2, 7, 11, 17, 19, 21, 22, 23, 63, 64).



HIERARCHICAL SYNTHESIS OF THE FORM

Because the subsystems in the lowest level of the hierarchy contained a convenient number of misfit factors (from 3 to 8), diagrams for the synthesis were commenced here.

The formal diagrams which satisfy the misfit factors and their links found in each subsystem in a level of the hierarchy were produced before an attempt was made to solve any subsystems in the next higher level. This method was used in order to avoid biasing subsystems by decisions made at a higher level. The synthetic process is thus continued until a diagram of a form satisfying the complete system of misfits and links is produced.

The synthetic process applied to the test problem, is illustrated in the following diagrams and explanations for that part of the hierarchy building up to subsystem A. It is significant that comprehensive analysis of a problem like the house, seemingly too simple to warrant this analytic process, reveals that even so-called trivial problems contain too many factors and interactions to be satisfactorily handled by the unassisted designer.

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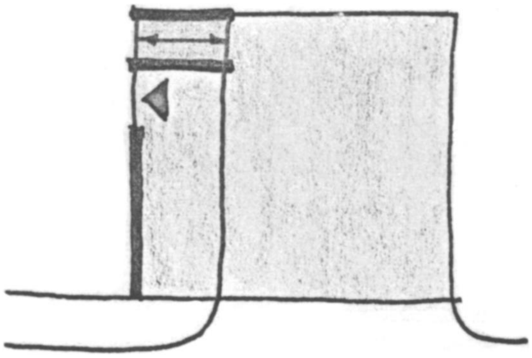
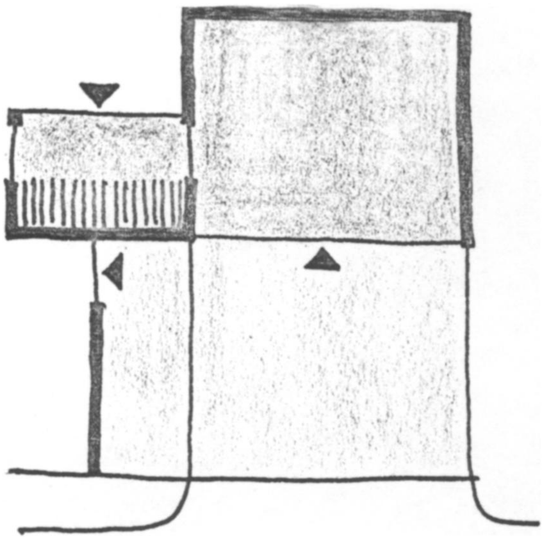
Diagram showing solution for Subsystem C. The architect begins by finding solutions for the subsets on the lowest level of the hierarchy by satisfying all the requirements in this subset (2, 7, 11, 21, 22).



SUBSYSTEM C — Misfit factors:

2. Large area to be snow-shovelled in winter.
7. No provision for reception of delivery, mail, parcels.
11. No protection during arrival and entry.
21. Difficult emergency access.
22. Difficult emergency escape.

Misfit factors 2 and 11 call for a roofed driveway, no longer than necessary for a car, and a separate roofed sidewalk for pedestrian arrival, walled on the side remote from the driveway. A wide sidewalk satisfied 21 and 22, providing ample space for emergency access and escape, even if the driveway is occupied. Misfit 7 suggests a delivery chute, opening to the driveway at its upper left corner for distinctness from the entry and convenience for the driver of the delivery vehicle.

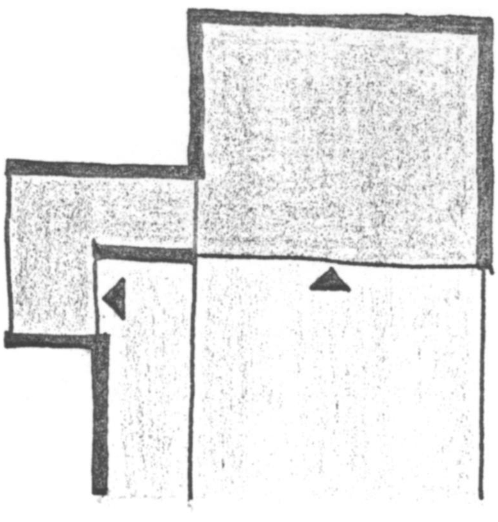


Solution for Subsystem D.

SUBSYSTEM D — Misfit factors:

1. Inadequate protection for cars.
2. Large area to be snow-shovelled in winter.
11. No protection during arrival and entry.
23. Access from car to dwelling involves long distance.
63. Poor provision for storage of gardening and exterior maintenance equipment.

Misfit factors 1, 2 and 11 call for a garage (preferably double), a roofed driveway slightly longer than a car, and a separate roofed sidewalk for pedestrian arrival, walled on the side remote from the driveway. Misfit factor 23 is best satisfied by entries to the dwelling on the driver's side, from both the driveway and the garage. A space for storage of gardening and exterior maintenance equipment, accessible from the dwelling's interior and opening on one side directly to the exterior and on the other through the entry from the garage solves Misfit factor 63, and provides a lock between the garage and dwelling to prevent transfer of fumes.



Solution for Subsystem E.

SUBSYSTEM E — Misfit factors:

1. Inadequate protection for cars.
11. No protection during arrival and entry.
19. Transmission of exterior noises.
23. Access from car to dwelling involves long distance.

Misfit factors 1, 11 and 23 call for a garage, roofed driveway, separate roofed sidewalk walled on the side remote from the driveway, and entries to the dwelling from the driver's side, from the driveway and the garage. Misfit 19 demands a buffer zone between the interior of the dwelling and the garage and exterior.

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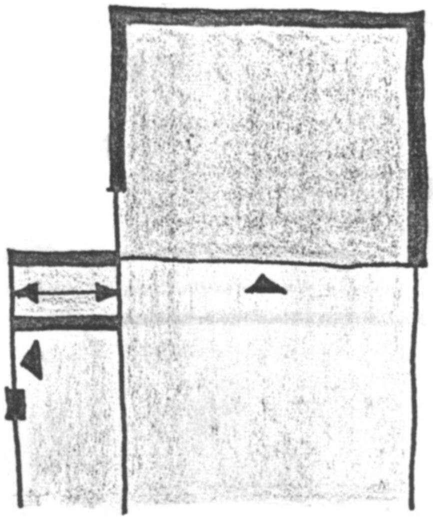
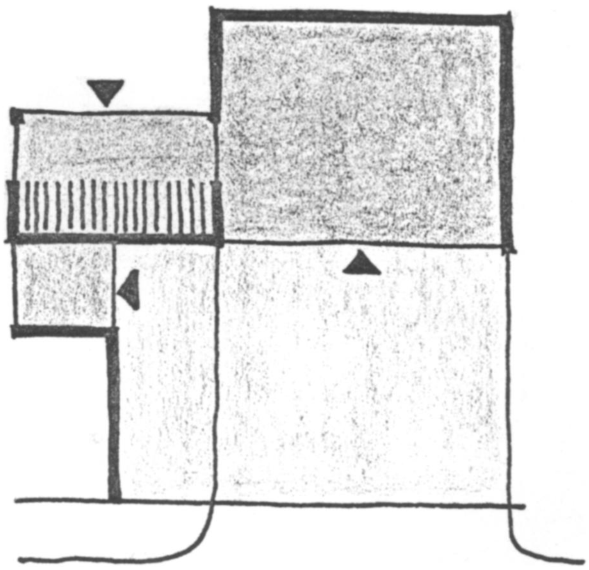
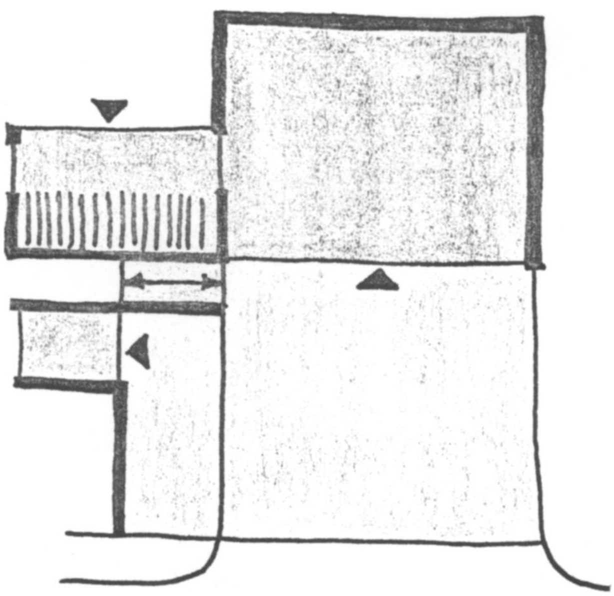
Solution for Subsystem F.



Solution for Subsystem B.



Solution for Subsystem A.



SUBSYSTEM F **Misfit factors:**

1. Inadequate protection for cars.
7. No provision for reception of delivery, mail, parcels.
17. No separation of children from vehicles.
23. Access from car to dwelling involves long distance.
64. No separation of pets from vehicles.

Misfit factors 1 and 23 call for a garage and entries to the dwelling from the driver's side, from both the driveway and garage. Misfit factor 7 is satisfied by a delivery chute opening at the upper left corner of the driveway, and misfit factors 17 and 64 by a play area separated from the driveway and road, and by a wide sidewalk to the dwelling entry.

SUBSYSTEM B *(Subsystems D plus E)*

The space for storage of gardening and maintenance equipment doubles as a noise buffer between the garage and dwelling, and a separate buffer is provided for the exterior entry.

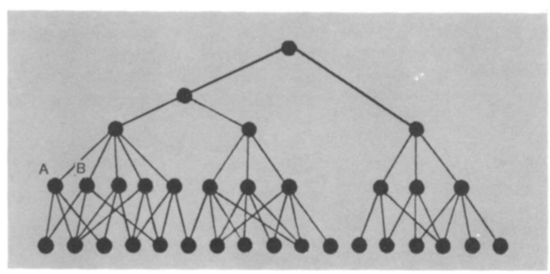
SUBSYSTEM A *(Subsystems B plus C plus F)*

The delivery chute and entry through the storage space from a service area are separated by an interior wall from the main entry to provide functional clarity.

THE RECOMPOSITION IS A LATTICE

It should be noted that the diagram of the hierarchical design program is itself a linear graph, whose points are the subsystems and whose edges join these subsystems and indicate the order of recomposition. The graph of this hierarchy, furthermore, does not represent the complete hierarchy of the problem, as it lacks the bottom level, the individual misfit factors and the lines joining them into subsystems which were generated by the initial run of the SIMPX program.

If, however, we include the bottom level (the individual misfits) of the hierarchy produced by the outlined method, the graph is no longer a pure tree, but assumes the form of the illustration below , as a result of common elements in some of the subsystems.



The design problem as a lattice. Requirements of Sub – systems A and B overlap in this diagram.

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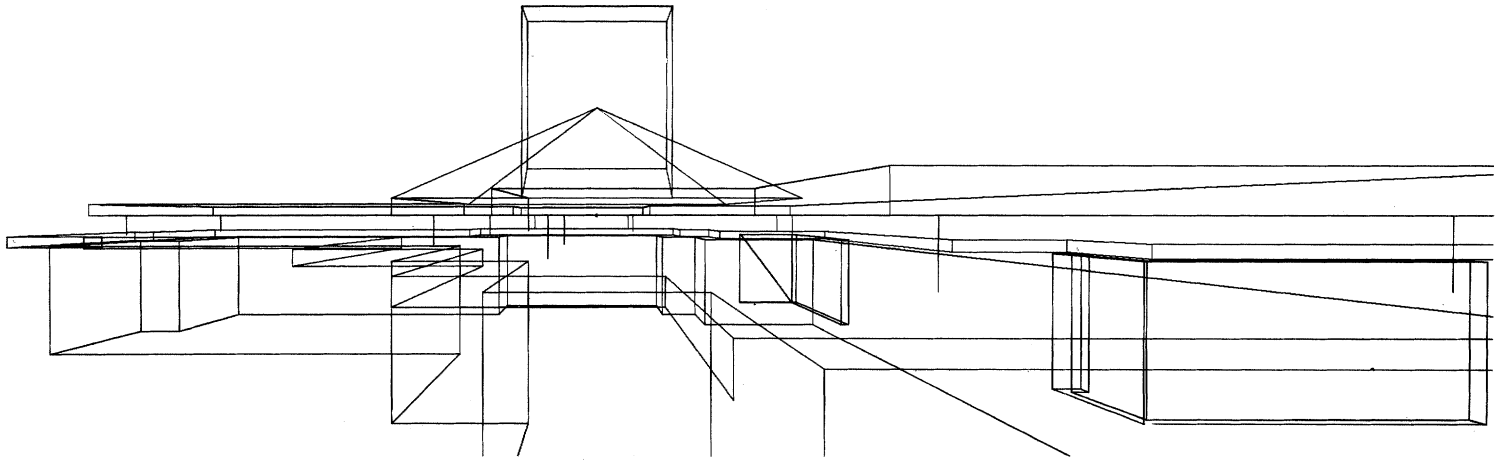
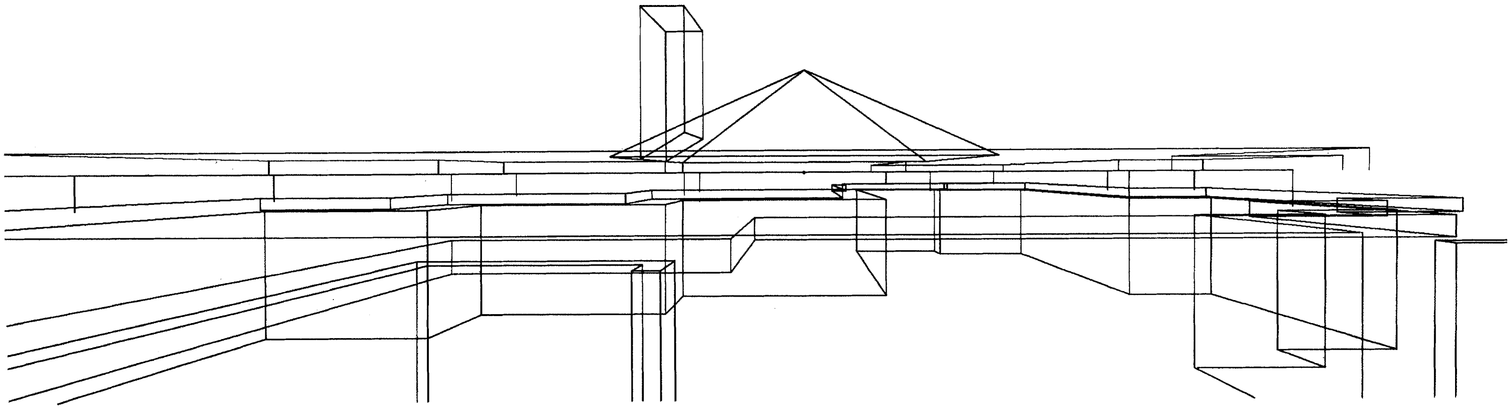
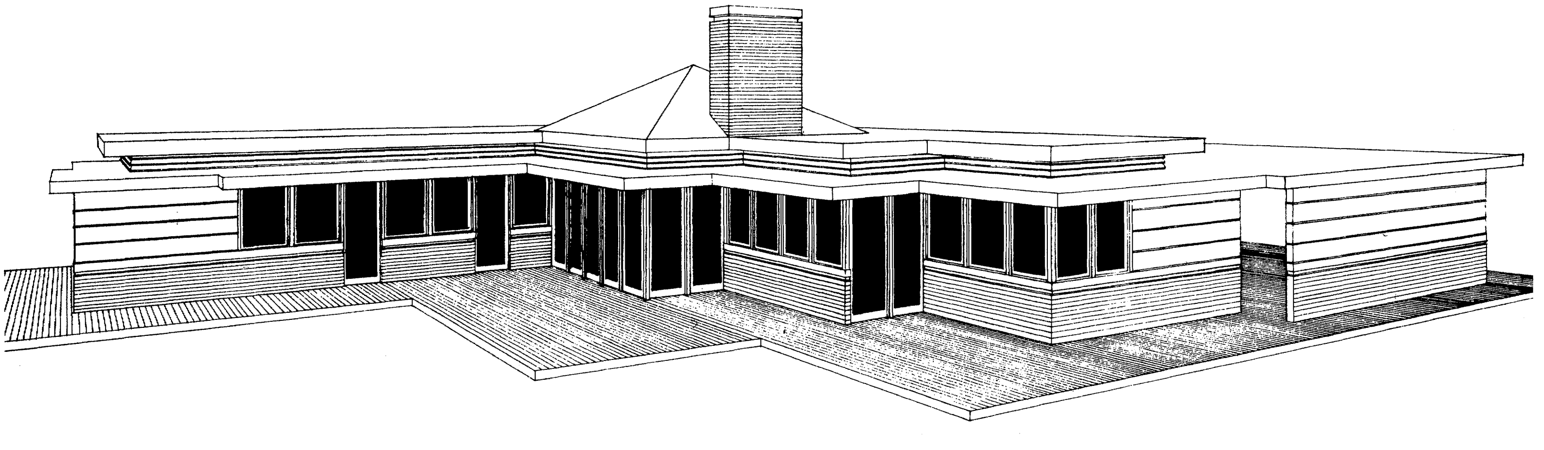




Above: Two computer drawings of different perspective views of the first stage of the house design. These preliminary views allowed the architect to pre-test the design and to correct areas which would have caused detailing difficulties.

Final rendering of the house design, based on the computer plot.



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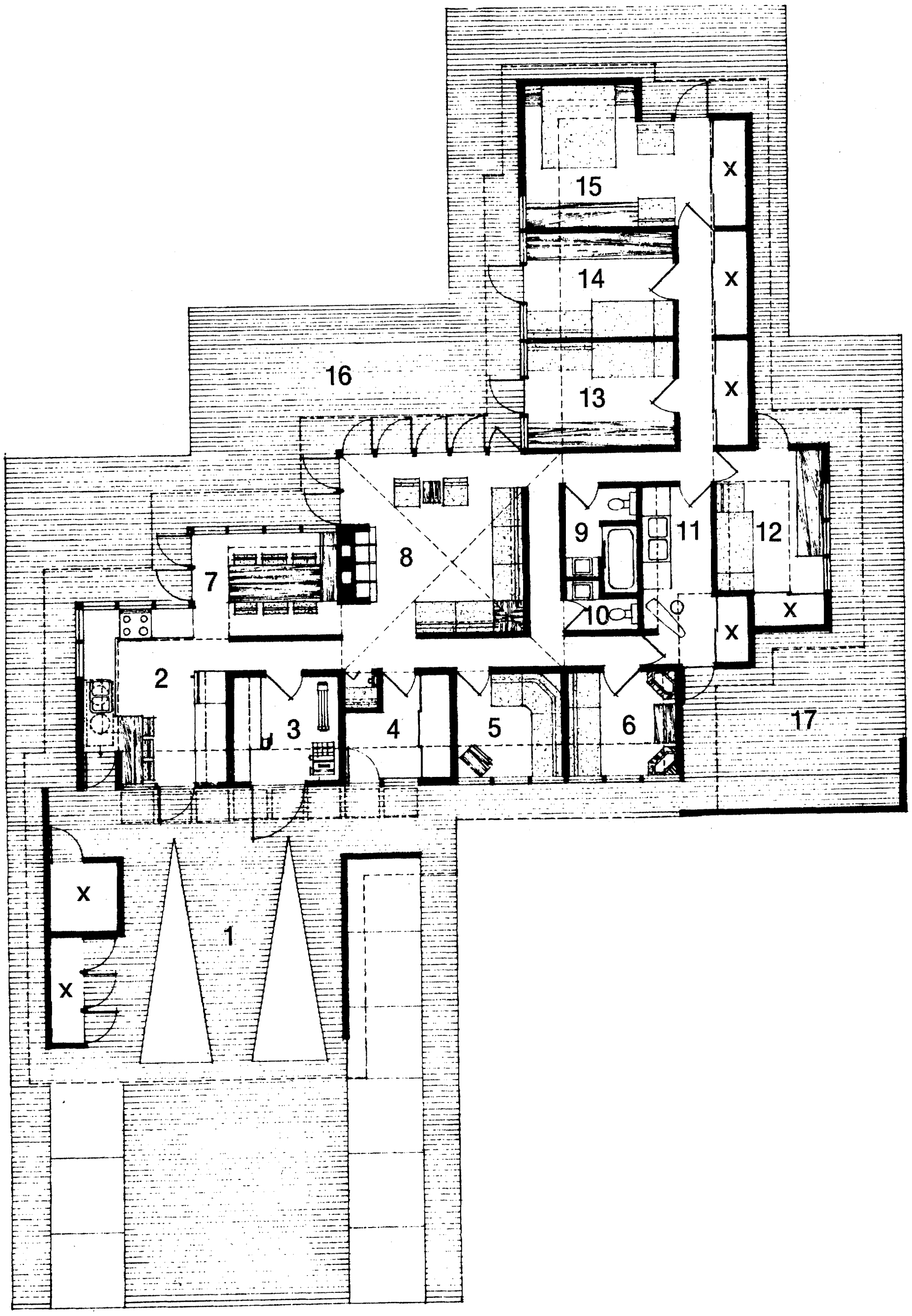

Ground plan:

1) Carport
2) Kitchen
3) Shop
4) Entry/storage
5) TV room
6) Sound room
7) Dining room
8) Living room
9) Bathroom
10) Washroom
11) Laundry, sewing, ironing room
12) Bed/study room
13) Bed/study room
14) Bed/study room
15) Master bedroom
16) Terrace
17) Drying yard
X) Storage

A design problem is by nature a lattice, that is, a structure with overlapping requirements. The fact is that in the conventional formmaking process the problem is not only based on artificial groupings of requirements, but is also considered to form a tree, with each requirement a member of a single "group," with none of them overlapping or interacting. This is a major weakness not corrected in the HIDECS 2 computer program and only potentially corrected in the programs called SIMPX and EQCLA. Yet, by manipulating the outputs of the SIMPX program and the BLDUP program and using them as data for further computer runs, a hierarchy based on a lattice may be produced.

The hierarchy yielded by this procedure is a formal statement of the design problem, and supports the contention that a problem clearly stated is half solved. But the procedure itself possesses no magical power. Its effectiveness depends on a thorough understanding of its use in the context of the entire design process. The designer must be able to provide a comprehensive set of misfit factors and their links, and to solve the hierarchy of subproblems in the specified order. The computer-aided analysis defines, but by no means shortens, the synthetic process. Such an analysis still demands unbiased, imaginative work by the form-giver.

This example shows how a formal picture of the design solution can be synthesized from a formal mathematical statement of the design problem. A recomposition of overlapping subsystems of the system of misfit factors and interactions into a hierarchy appears to be a valid model for the synthesis of form.

It is not suggested here that the process described will yield one perfect final form, but it is clear that a form which reflects a correctly synthesized formal solution will possess both unity and clarity of purpose. A single problem analyzed in this way might yield many such forms.

In addition to the above procedure, the designer has other opportunities to use the computer as a partner in improving our environment. For instance, the designer can, by using automatic drafting equipment, pre-test and evaluate his creations on a dry-run, pre-construction basis, as jet manufacturers already do today. This means that these built-in correction factors in the actual drawing stage will permit the designer to make every job a custom-tailored affair.

Even if we consider the computer simply as a high-powered drafting machine, this in itself is very significant. It will free creative architects for the high-level tasks for which their training ought to prepare them, rather than relegate them to reproducing volumes of repetitious drawings. In fact, the computer may enable man to pursue those roles which are uniquely human.

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