1 INTRODUCTION

Building design is distinguished from other fields of design endeavour by three significant characteristics:

a) the magnitude of the "solution space" (e.g. there are some seven million ways of arranging 12 spatial units within a 3 x 2 x 2 unit envelope),

b) the multi-variate nature of the problem (e.g. the need to satisfy structural, servicing, functional, aesthetic and other performance requirements), and

c) the temporal variation in objectives over the lifetime of the building.

Reluctance or inability to face the problems arising from these characteristics has led, respectively, to:

a) a retreat into stylism (the magnitude of the solution space being thus reduced to a sub-set representing the arbitrary but currently accepted consensus among the self-appointed architectural cognoscente),

b) a strict hierarchical ordering of design decisions (in which 'form' is crystallised prior to, and independent of, structure which in turn is crystallised prior to, and independent of, service distribution, etc.),

c) a perverse commitment to a single concrete 'statement' in terms of built form (resulting in buildings in which the mismatch between need and provision starts the day after the building is opened and increases daily thereafter).

This paper, based on the assumption that the difficulties arise from inability rather than reluctance, proposes a tentative computer mechanism which is designed to enhance the ability of all members of the building design team to a degree to which these problems can be faced, and with goodwill, solved.

2 THE COMPUTER AND THE DESIGN ACTIVITY

The application of the computer to disparate facets of the building design activity is increasing at a gratifying rate. At a recent conference held by the Committee for the Application of Computers in the Construction Industry (CACCI) each professional subcommittee reported on the growth of computer usage; architects can now choose from half a dozen programs for minimising layout on the basis of circulation; structural engineers can perform incredible feats of computational virtuosity for beam and column sizing; there is such a multiplicity of pipe sizing programs for services engineers that 'which-like' reports have to be produced to compare effectiveness.

Gratifying indeed, but: is circulation a significant performance criterion; does faster beam sizing have any payoff other than to consulting engineers where is the virtue in reducing pipe costs by 2% for a layout in which the spatial configuration is so inept from the point of view of service distribution that it should never have been mooted in the first place? Each profession, within its own discipline, has been using the computer primarily as a number-cruncher - i.e. to undertake standard routines more rigorously and faster than was possible previously by purely manual means. Programs which deal with decision-making at the early strategic stages in design, where the interaction between the building sub-systems is maximum and the consequences have the greatest significance to the overall optimisation of the building performance, are virtually non-existent.

The computer mechanism proposed in this paper is an attempt to introduce the power of the computer to the design activity at the earliest possible moment; as such it has considerable significance for the method of design working and the relationship between each member of the design team.

Observation of the architectural design activity [1] has suggested a model, such as that represented in Figure 1, in which the sequential stages in the activity - Outline Proposals, Scheme Design and Detailed Design - each contain three processes - ANALYSIS, SYNTHESIS and APPRAISAL. Consideration of the role the computer might play in design (see ABACUS Occasional Papers 1 and 10) [2,3] leads to the conclusion that the best payoff will come from its application to the process of appraisal.

The act of appraisal is considered to comprise three stages:

REPRESENTATION	-	the formulation of a model of the proposed solution,
MEASUREMENT	-	the prediction of the performance characteristics of each relevant variable, and
EVALUATION	-	the comparison of the cost and performance characteristics of the proposed scheme with some set of criteria.

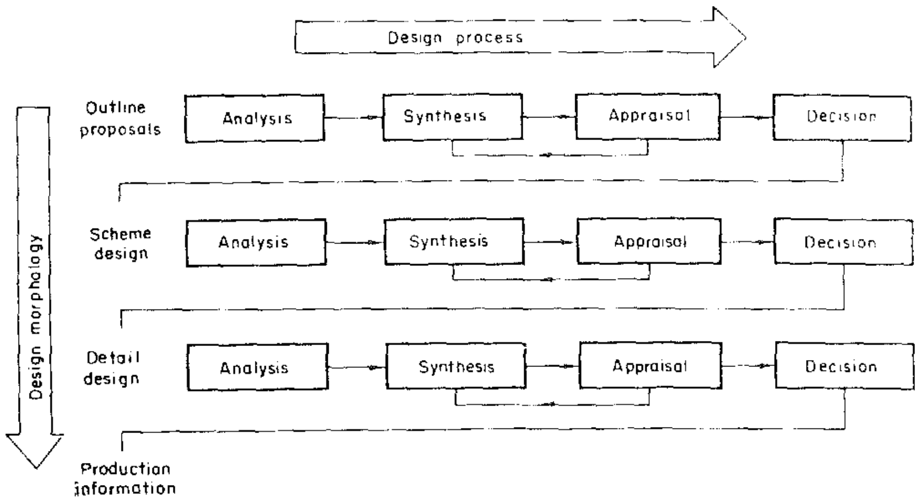

FIGURE 1 Model of the Design Activity

The criteria relevant to the evaluation process can take the form of constraints (which may be statutory or set by the client organisation), norms (built up from previous schemes of similar type) or optima (generated for each performance variable individually).

Working in the traditional mode, the designer (or the designer team) carries out the process of analysis and, on the basis of this, conceives a design synthesis; at this point, rudimentary appraisal may take place. The process of appraisal is rudimentary because thorough appraisal is laborious, time-consuming and demanding in specialist skills. From the rudimentary appraisal, some modifications to the synthesis may be indicated and implemented but rather than undertake the onerous task of re-appraisal, it is likely that the designer will move immediately to the next more detailed stage in the design activity.

Few designers would deny the inadequacy of this mode of working; the inability to examine more than a very few alternative schemes at any stage and the conscious or unconscious failure to check all but what are arbitrarily considered to be the few most important aspects of the functioning of the scheme, makes adequate design, let alone good design, something of a lottery.

Hence the concept of a set of three computer appraisal packages - one for stage C (Outline Proposals) one for stage D (Scheme Design) and one for stage E (Detailed Design) in the RIBA Plan of Work which will allow the designer rapidly to appraise a large number of alternative schemes, each appraisal dealing with all quantifiable aspects of the scheme relevant to the current stage in the design activity.

ABACUS has been concerned with the production of sets of appraisal packages - generically called PACE - each set dealing with a specific building type. The following section of this paper deals, as an exemplar, with PHASE 1, a package for the appraisal of hospitals at the Outline Proposals stage in design. The package owes its origin to Kernohan, Rankin, Wallace and Walters who are currently developing it within the ABACUS team. The program can be accessed by practitioners through LINK [4].

3 PHASE 1

The package PHASE 1 is written in Fortran IV for use on any on-line time-sharing computer system. Interaction with the computer is by means of a teletypewriter or direct view storage tube terminal connected to the main-frame machine over ordinary voice-grade telephone lines. The program initiates a dialogue with the user and formats the output in such a way as to facilitate the designers appreciation of the results.

The package, which uses the ASP data structure, consists of: a standard data file, a project file and a geometry file (for REPRESENTATION of the scheme); a solution file (for EVALUATION of the scheme); and a program executive (for MEASUREMENT of the scheme). The following sub-sections discuss these constituent parts.

3.1 Standard Data File

The standard data file contains information on environmental conditions, costs and interdepartmental functional associations. Where relevant these data are stored for each of 40 individual hospital departments (e.g. X-Ray, OPD, Pharmacy, etc.).

Environmental Data: air change rates; occupancy numbers; hours of occupancy; percentage wall glazing; percentage roof glazing; day and night external temperatures; solar heat gains; thermal transmittance values; lighting levels.

Cost Data: building capital costs; services capital costs; fuel tariffs; interest rates; building life.

Association Data: a matrix of the association values between each pair of the 40 hospital departments.

When a design practice first accesses the package, the information contained in the standard data file is that available from Hospital Building Notes, the Institution of Heating and Ventilating Engineers' Guide to Current Practice and other published sources. The file may be inspected and, if the designer so wishes, modified appropriately. Once modified (or accepted as it stands), it may remain unaltered over a large number of design projects.

3.2 Project File

Into this file is fed, at the start of a design programme, information relating to the contours and orientation of the project site. The contour information is formatted by imagining a grid placed over the site (the courseness of the grid depending on the uniformity of the site) to each cell of which is associated a spot height above sea level. These spot heights are fed into the project file together with the angle of orientation of the grid to the north point.

This filed information remains constant throughout the design project but will of course change from project to project.

3.3 Solution File

The function of the solution file is to store the cost and performance characteristics of previous projects (N) and of earlier schemes relating to the current project (P). These data may be accumulated automatically in a manner which will be described later.

3.4 Geometry File

Into this file is fed the three-dimensional geometrical form of any hypothesised scheme (Figure 2). The file may be created on-line at the teletype terminal by typing in, for each floor of each department, the departmental code together with the plan coordinates of two opposing vertices, relative to the origin of the site grid; using the graphics terminal the file can be created on-line by use of the cursor which allows positioning on the screen of any of the departments. As an alternative the geometrical data

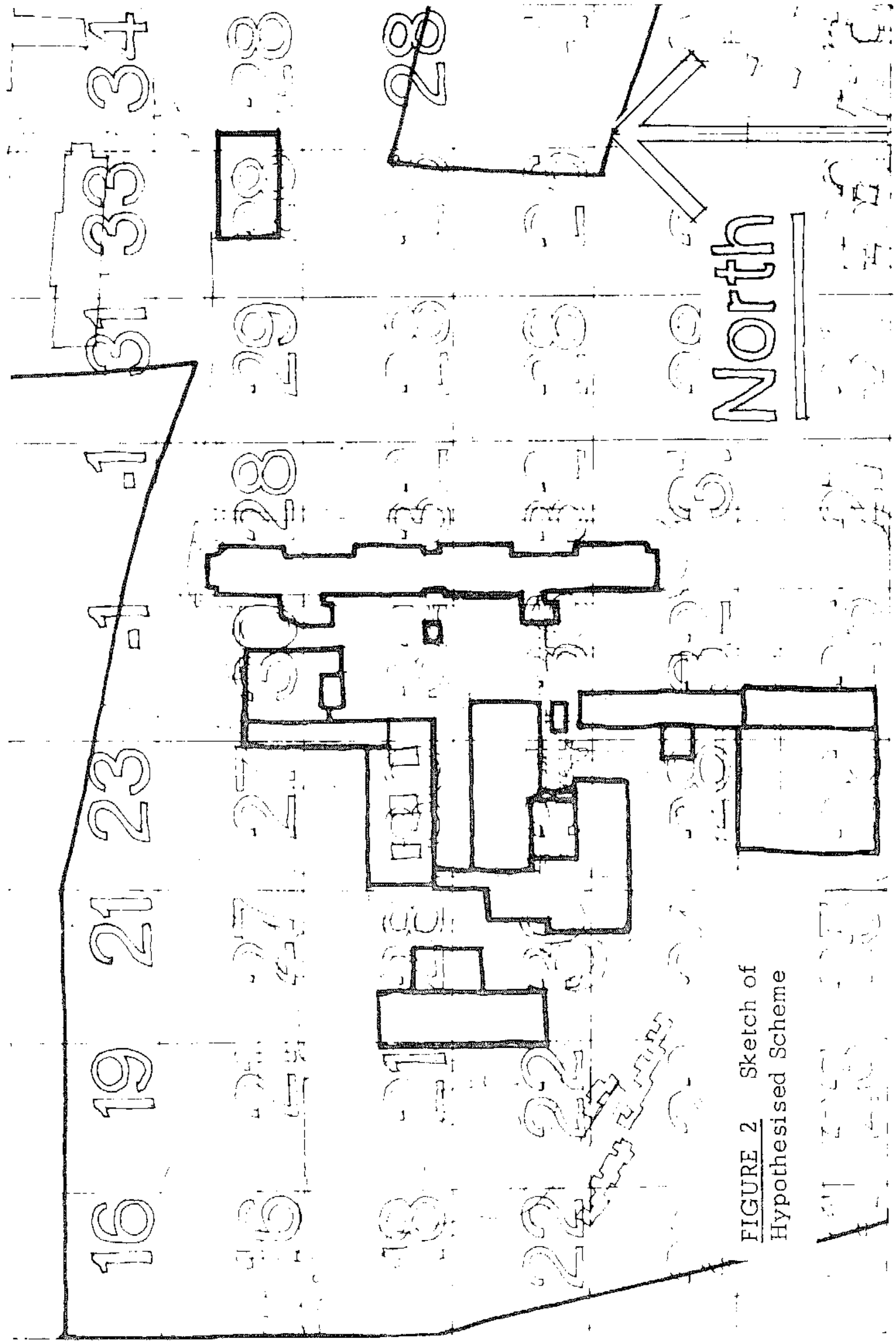

FIGURE 2 Sketch of Hypothesised Scheme

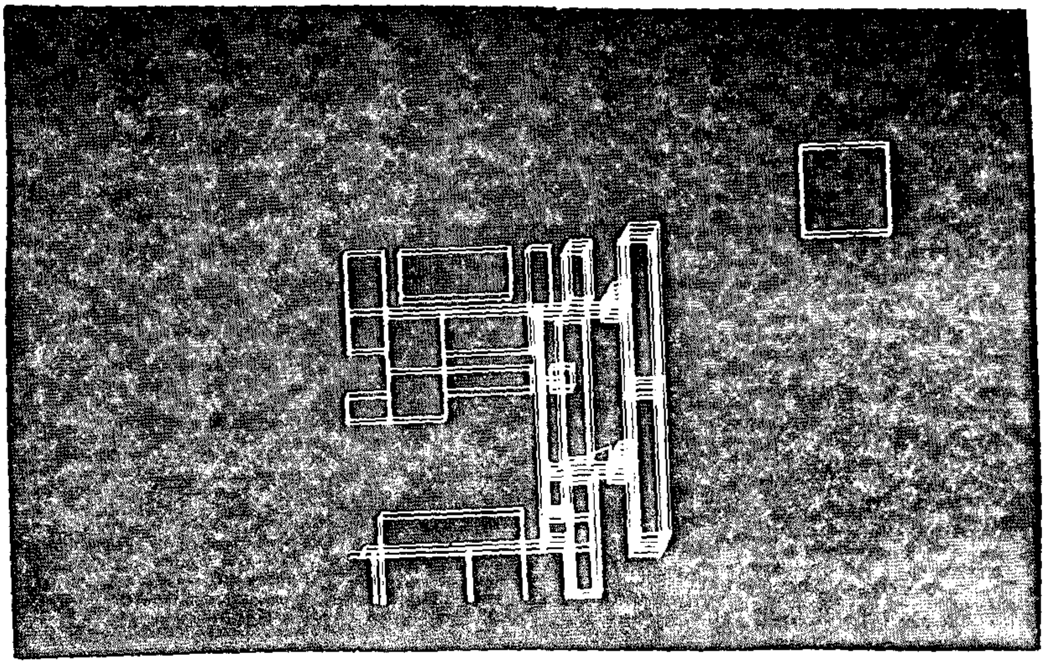

FIGURE 3 Axonometric View Photographed from DVST

can be generated off-line by producing paper tape at the teletype and subsequently feeding the tape data into file.

3.5 Program Executive

When the program is called up on the system, the user is asked to identify the code numbers of the files to be used, i.e. the standard data file, the project file, the solution file and the geometry file. When running the program from a graphics terminal the user is then given the opportunity of viewing the scheme in plan or axonometrically (Figure 3); at this point the option is offered of making alterations to the geometry of the scheme by modifying the geometry file.

When the user is satisfied that the geometry file properly represents his hypothesised solution, i.e. that the computer understands his design intent, the program enters the 'output' mode.

Synoptic Output: the synoptic output (Table 1) consists of descriptors of the scheme geometry followed by indices of plot ratio, site utilisation, compactness, planning, capital cost and

TABLE 1 (continued on following 7 pages)

Printout from PHASE 1

OUTPUT - SYNOPTIC

AREA - TOTAL FLOOR	51609.				
AREA - FLOOR -2	16137.				
AREA - FLOOR -1	9788.				
AREA - FLOOR 0	16452.				
AREA - FLOOR 1	5064.				
AREA - FLOOR 2	4168.				
AREA - EXTERNAL WALL	20893.				
AREA - ROOF	38827.				
WARD - NORTH WALLS	4.%				
WARD - SOUTH WALLS	4.%				
WARD - EAST WALLS	49.%				
WARD - WEST WALLS	42.%				
WALL/FLOOR RATIO	.40	.00	.00	.00	.00P
		.00	.00	.00	.00N
PLOT RATIO	3.14	.00	.00	.00	.00P
		.00	.00	.00	.00N
SITE UTILISATION	.04	.00	.00	.00	.00P
		.00	.00	.00	.00N
PLAN COMPACTNESS	14.18	.00	.00	.00	.00P
		.00	.00	.00	.00N
MASS COMPACTNESS	15.10	.00	.00	.00	.00P
		.00	.00	.00	.00N
LIFT DEPENDENCY FACTOR	816	0	0	0	0P
		0	0	0	0N
DEPARTMENT LOCATION PER BED	7302.	0.	0.	0.	0.P
		0.	0.	0.	0.N
BOILERHOUSE LOCAT. PER BED	1355.	0.	0.	0.	0.P
		0.	0.	0.	0.N
INDIC. CAPITAL COST PER BED	9266.	0.	0.	0.	0.P
		0.	0.	0.	0.N
INDIC. ENERGY COST PER BED	254.	0.	0.	0.	0.P
		0.	0.	0.	0.N

DO YOU WISH A PRINTOUT OF (1)ALL DETAILED OUTPUT (2)PART OF DETAILED OUTPUT (3)NO DETAILED OUTPUT

1

DEPARTMENT LOCATION

41 HIGHEST POSITIVE ASSOCIATIONS

DEPARTMENT 1	DEPARTMENT 2	DIVERGENCE
SURGICAL	OP THEATRES	4.21
OP THEATRES	SURGICAL	4.21
OP THEATRES	SURGICAL	4.21
THEATRES	SURGICAL	4.15
THEATRES	SURGICAL	4.15
THEATRES	SURGICAL	4.15
SURGICAL	XRAY	4.14
XRAY	SURGICAL	4.14
XRAY	SURGICAL	4.14
SURGICAL	SHORT STAY	3.61
SHORT STAY	SURGICAL	3.61
SHORT STAY	SURGICAL	3.61
OP THEATRES	SURGICAL	3.52
PAEDIATRIC	OP THEATRES	3.49
SURGICAL	A & E	3.40
A & E	SURGICAL	3.40
A & E	SURGICAL	3.40
PHYS. MED.	MIXED	3.30
PHYS. MED.	MIXED	3.30
THEATRES	A & E	3.24
XRAY	SURGICAL	3.22
SURGICAL	PHYS. MED.	3.16
PHYS. MED.	SURGICAL	3.16
PHYS. MED.	SURGICAL	3.16
SHORT STAY	SURGICAL	3.06
GERIATRIC	PHYS. MED.	2.91

THEATRES	MIXED	2.89
THEATRES	MIXED	2.89
OP THEATRES	MIXED	2.88
OP THEATRES	MIXED	2.88
PAEDIATRIC	XRAY	2.81
PAEDIATRIC	PHYS. MED.	2.78
A & E	SURGICAL	2.73
SURGICAL	MAIN ENT.	2.62
MAIN ENT.	SURGICAL	2.62
MAIN ENT.	SURGICAL	2.62
THEATRES	SURGICAL	2.58
PHYS. MED.	MAIN ENT.	2.55
PHYS. MED.	SURGICAL	2.47
A & E	MIXED	2.38
A & E	MIXED	2.38

41 HIGHEST NEGATIVE ASSOCIATIONS

DEPARTMENT 1	DEPARTMENT 2	DIVERGENCE
PHARMACY	DINING	-.97
NURSE TRAIN	MIXED	-.97
NURSE TRAIN	MIXED	-.97
NURSE TRAIN	MEDICAL	-.97
DINING	MORTUARY	-.98
KITCHEN	ADMIN.	-.98
PHARMACY	CHAPEL	-.98
STAFF CHANGE	ADMIN.	-.98
STAFF CHANGE	MAIN ENT.	-.98
STAFF CHANGE	PSYCHIATRIC	-.98
ITU	STAFF CHANGE	-.98
MORTUARY	ADMIN.	-.98
PSYCHIATRIC	MIXED	-.98
PSYCHIATRIC	MIXED	-.98
PSYCHIATRIC	MEDICAL	-.98

GERIATRIC	MIXED	-.98
GERIATRIC	MIXED	-.98
GERIATRIC	MEDICAL	-.98
GERIATRIC	PSYCHIATRIC	-.98
PAEDIATRIC	SURGICAL	-.98
PAEDIATRIC	SURGICAL	-.98
PAEDIATRIC	SURGICAL	-.98
PAEDIATRIC	SURGICAL	-.98
MAIN ENT.	ADMIN.	-.99
MAIN ENT.	NURSE TRAIN	-.99
STAFF CHANGE	NURSE TRAIN	-.99
OP THEATRES	CHAPEL	-.99
MORTUARY	CHAPEL	-.99
OPD	CHAPEL	-.99
LABORATORY	CHAPEL	-.99
A & E	CHAPEL	-.99
STAFF CHANGE	CHAPEL	-.99
PHYS. MED.	CHAPEL	-.99
CHAPEL	ADMIN.	-.99
NURSE TRAIN	CHAPEL	-.99
THEATRES	STAFF CHANGE	-.99
XRAY	CHAPEL	-.99
ITU	CHAPEL	-.99
THEATRES	CHAPEL	-1.00
MED. RECORDS	CHAPEL	-1.00
MED. PHOT.	CHAPEL	-1.00

BOILERHOUSE LOCATION

DEPT.	LOAD FACTOR	DEPT.	LOAD FACTOR
1	-1.00	2	.03
3	.66	4	.64
5	.59	6	-.55
7	-1.00	8	-.75
9	-.83	10	-1.00
11	-1.00	12	3.14
13	13.90	14	-.67
15	-.67	16	-.36
17	-.88	18	-1.00
19	-.89	20	2.91
21	-1.00	22	.93
23	4.51	24	-.14
25	-.95	26	.31
27	-.80	28	-.62
29	-.87	30	-1.00
31	-1.00	32	-1.00
33	-.87	34	-.91
35	-.82	36	-1.00
37	-.43	38	-.60

CAPITAL COSTS (DETAILED)

ELEMENT	QUANTITY	RATE	PRES. WORTH	ANL. EQUIV.
GROUND FLOOR (M2)	16452.	6.	98712.	7478.
VOLUME OF CUT (M3)	23143.	1.	23143.	1753.

VOLUME OF FILL	89091.	1.	89091.	6749.
(M3)				
UPPER FLOORS	35157.	4.	140628.	10654.
(M2)				
ROOF	38827.	3.	116482.	8824.
(M2)				
ROOFLIGHTS	484.	10.	4838.	367.
(M2)				
EXTERNAL WALLS	14994.	4.	59976.	4544.
(M2)				
WINDOWS	5904.	15.	88565.	6709.
(M2)				
FLOOR FINISHES	51609.	2.	103218.	7820.
(M2)				
CEILING FINISHES	51609.	2.	103218.	7820.
(M2)				
BOILER PLANT	6231.	10.	62308.	4720.
(KW)				
CORE VENT. PLANT	149.	600.	89312.	6766.
(M3/SEC)				
TEMP. VENT. PLANT	9023.	600.	5413903.	410144.
(M3/SEC)				
AIR COND. PLANT	25.	1694.	42282.	3203.
(M3)				
P.S.A.L.I.	25115.	2.	50230.	3805.
(M2)				
		TOTALS	6485906.	491356.

INDICATIVE ENERGY COSTS (DETAILED)

HEATING (KW)	753681.	.010	7537.	571.
LIGHTING (M2)	25115.	.370	9293.	714.
CORE VENTILATION (M3/YEAR)	756374.	.010	7564.	573.
TEMP. VENTILATION (M3/YEAR)	15158925.	.010	151589.	11484.
AIR CONDITIONING (M3)	82694.	.020	1654.	125.
		TOTALS	177636.	13457.

HEAT LOADS

MAXIMUM HEATING LOAD = 4380. OCCURS DURING MORNING JAN
MINIMUM HEATING LOAD = 227. OCCURS DURING EVENING JUL
MAXIMUM COOLING LOAD = 2573. OCCURS DURING AFTERNOON JUL
FOR HOW MANY COMPONENTS DO YOU WISH HEAT GAIN/LOSS DIAGNOSTICS
2
WHICH COMPONENTS
21,22

DEPARTMENT NO. 21 - A & E

MONTH	MORNING	AFTERNOON	EVENING	NIGHT
JAN :	-0.	-15.	1.	27.
FEB :	-1.	-18.	-0.	27.
MAR :	-10.	-32.	-9.	11.
APR :	-20.	-45.	-20.	2.

MAY :	-32.	-66.	-33.	-11.
JUN :	-52.	-80.	-53.	-30.
JUL :	-65.	-36.	-65.	-43.
AUG :	-63.	-85.	-63.	-42.
SEP :	-53.	-75.	-52.	-31.
OCT :	-37.	-55.	-36.	-15.
NOV :	-18.	-34.	-17.	4.
DEC :	-9.	-21.	-8.	11.

DEPARTMENT NO. 22 - PHYS. MED.

MONTH	MORNING	AFTERNOON	EVENING	NIGHT
JAN :	157.	35.	33.	42.
FEB :	156.	26.	31.	42.
MAR :	144.	6.	18.	36.
APR :	131.	-11.	3.	32.
MAY :	113.	-36.	-15.	26.
JUN :	87.	-54.	-42.	18.
JUL :	[illegible]	-64.	-58.	13.
AUG :	71.	-65.	-56.	13.
SEP :	[illegible]	-53.	-40.	18.
OCT :	107.	-23.	-17.	25.
NOV :	133.	[illegible]	9.	33.
DEC :	145.	25.	21.	36.

```
 DO YOU WISH TO CHANGE GEOMETRICAL INPUT DATA       0/1
0
 DO YOU WISH TO STORE SCHEME IN FILE       0/1
0
 DO YOU WISH TO UPDATE SOLUTION FILE       0/1
0
 DO YOU WISH TO UPDATE NATIONAL FILE       0/1
0
 END OF PROGRAM
```

energy cost. Of these, perhaps the two planning indices - departmental location and boilerhouse location - need some explanation. In the case of departmental location the index measures the disparity in inverse proportionality between the association values contained in the standard data file and the actual distances between departments. In the case of the boilerhouse location the index measures the disparity in inverse proportionality between the computed services loads in each department and their distance from the boilerhouse. The four additional columns of output are the values from the solution file for previous projects (lower line - N) and previous tentative solutions to the current problem (upper line - P); these are produced to allow comparative evaluation of the current scheme.

Detailed Output: at the conclusion of the synoptic output the opportunity is given (Table 1) to obtain a more detailed output. Under the heading of 'departmental location' the pairs of departments which have significantly contributed to this performance index are identified; high divergence values indicate that the departments have been sited too far apart, low divergence values indicate that departments have been located closer together than is necessary. Under the heading 'boilerhouse location' those departments in relationship to which the boilerhouse is most badly placed are identified. Capital cost details are output for 14 elements in present worth and annual equivalent terms as are running costs for heating, lighting, ventilation and air conditioning. The detailed output concludes with the net gains and losses (losses indicated by a negative sign) at four times of an average day in every month, for any specified department.

Following the detailed output, or following the synoptic output if no detailed output is required, the computer asks a number of questions (Table 1). The first question allows the user to modify the form of his scheme by allowing changes in the geometry. The opportunity therefore exists to iteratively converge on a solution which, on the basis of the output measures, seems best.

The second question simply allows the user to hold the scheme, in its current state of development, until some future occasion.

The third and fourth questions provide the user with the opportunity to add his current scheme into the solution file, either the part referring to previous projects (lower line - N - in synoptic output) or the part referring to previous solutions to the current problem (upper line - P).

4 USE

There are two main uses to which a package such as PHASE 1 may be put. The first is in the context of a live design project. Irrespective of which member of the design team generates the first design hypothesis, an explicit appraisal is produced of the cost and the spatial, environmental and functional characteristics. If each member of the design team has a terminal in his own office, it is open to him to effect modifications to the original hypothesis; the original concept and any modifications are therefore accessible to all members of the team. For every modification the cost and performance attributes can be evaluated by comparing them with the mean value of all previous schemes of similar type. The speed with which modifications can be effected ensures that a vast area of the feasible 'solution space' can be searched for that solution which represents the optimum compromise between conflicting performance requirements. Moreover, the implications of future change - in type of occupancy, size, functional interdependence, etc. - can be examined from the outset to ensure a design solution which is temporally robust.

The second context is primarily an educational one. The relationship between any pair of building design variables, such as daylight and heat loss, is not readily formulated, a priori, because of the very complex physical laws pertaining; equally the relationship is almost impossible to establish from measurement of existing buildings because of the host of other variables in play. A program package like PHASE 1, which can simulate, in a controlled way, a large number of alternative solutions in a very short space of time, offers a unique chance to study the causal relationships which govern building performance. For example, geometry can be systematically varied to establish, from the output, the relationship between compactness and running costs; glazing areas can be varied in the standard data file to determine the effect on thermal performance, etc.

Whatever use the package is put to, a significant feature is the solution file containing the data bank of the cost and performance characteristics of previous schemes, which can be constantly accessed and continuously updated.

5 IMPLICATIONS FOR DESIGN AND FOR THE PROFESSION

At the outset this paper identified three unique characteristics of the building design activity - the magnitude of the solution space, the multi-variate nature of the problem and the temporal variation in

objectives. The claim for the PACE series of programs is that, potentially, they offer a means of coping with these three problem areas:
a) a massive number of alternative solutions can be proposed and tested;
b) appraisals of all the main criteria - financial, spatial, environmental and functional - are output from the word go; c) the implications of changing needs can be simulated during the design period, and for that matter, throughout the building life.

Any mechanism which makes a claim to tackle the problems which lie at the very heart of the building design activity must impinge on the territorial imperatives of professional identity. As stated earlier, the tradition pattern of building design has been for the architect to manipulate the built form until he had satisfied himself, on whatever implicit criteria he held dear, that he had a 'good' solution; then, and only then, the services engineer or the structural engineer or the quantity surveyor scurried off and returned, slide-rule smoking, with some check figures. At worst, the architect, meanwhile more than ever committed to his form, ignored the figures; at best he reneged and restarted the lengthy cycle. With the approach implied by PACE, this can no longer be possible: in the first place some at least of the environmental and financial implications are produced in black and white from the outset (the program is structured to preclude selectivity in the output); in the second place the consultant members of the design team are relieved of much of the chore of checking.

What this means is that the other members of the design team, as we now know them, are free to play a much more creative role in the early stages of design decision-making. Why should they not, in their own office at their own terminal, contribute to the optimisation of the built form in common with the architect?

Change in the emphasis of the application of the computer from the number-crunching routines in each disparate profession to the decision-making heuristics in the early stages in design must, in the long run, fundamentally destroy the profession delineations which currently exist. We are <u>all</u> building designers, we <u>all</u> have a responsibility for the built environment.

6 ACKNOWLEDGEMENTS

The author is pleased to acknowledge that PHASE 1 owes its origin to the efforts of D. Kernohan, G. Rankin, G. Wallace and R. Walters during their year of postgraduate study in the Department of Architecture and Building Science, University of Strathclyde; program writing was undertaken by members of ABACUS, in particular by Mrs. M. Unsworth. Financial support was provided by the Science Research Council and the Scottish Home and Health Department.

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4 LINK is a network of organisations engaged in CAAD research and development. In Scotland each is connected to the multi-access UNIVAC 1108 operated by the National Engineering Laboratory at East Kilbride. Applications programs are pooled and are available for dissemination to architectural practitioners throughout the U.K.