PACE 1 : AN ON-LINE DESIGN FACILITY

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Introduction

PACE 1 is an interactive computer program to be used for the appraisal of buildings at an early stage in their design. The package is the outcome of a year's work financed by a grant from the Royal Institute of British Architects and carried out by the Architecture and Building Aids Computer Unit, Strathclyde (ABACUS) at the University of Strathclyde's Department of Architecture and Building Science.

The Concept of Appraisal

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

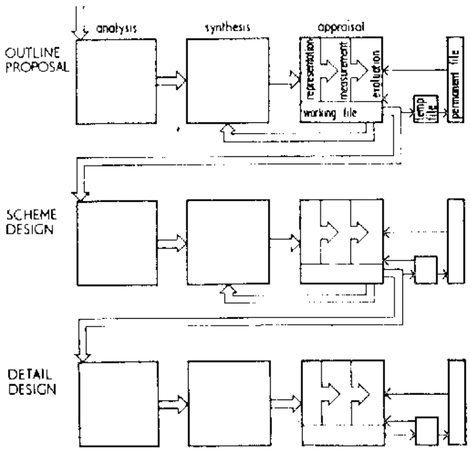

Figure 1

computer might play in design (see ABACUS Occasional Papers 1 and 10),(2),(3) leads to the conclusion that the best pay-off will come from its application to the process of appraisal. 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. The main purpose of this paper is to describe the form and use of PACE 1, a general package for the Outline Proposals stage.

The Form and Use of PACE 1

PACE 1 (PACE = Package for Architectural Computer Evaluation) is designed to be used at the 'Outline Proposals' stage of the building design activity. The package is written in Fortran IV and runs on the time-sharing system operated by Systemshare Limited. Input is by means of a teletypewriter terminal and connection to the central processor is by means of GPO telephone lines. One pass of the program costs about $10.

As the input and output formats will show, the mode of interaction between the designer and the computer is 'conversational' with the machine taking the initiative. The responses from the designer may be typed directly onto the keyboard as the program runs, prepared before-hand on paper-tape which automatically feeds in data as required by the program, or written to file.

To illustrate the form and use of the package, a simple example will be taken. Consider a school building made up of 6 primary functional units (called components in the terminology of the programme). Figure 2 gives the relationship

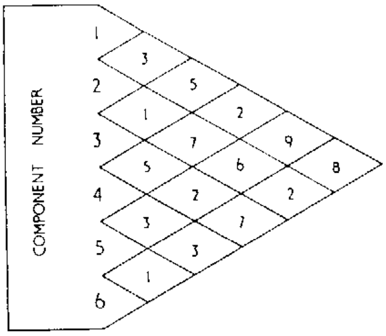

Figure 2

on a scale 0 - 10 between the functional units or components on whatever basis the designer considers appropriate. Figure 3 is the

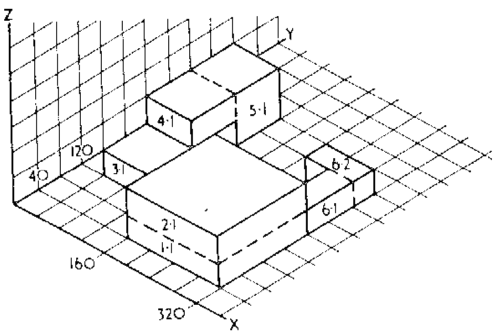

Figure 3

designer's initial conception of the scheme in relation to the site (Figure 4) with the volumes labelled in accordance with Figure 2. Components 1 to 5 are all rectilinear and can therefore be considered to be made up of only one element; component 6 is 'L-shaped' and is

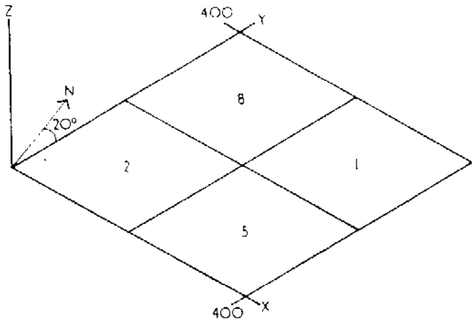

Figure 4

made up of two rectilinear elements - 6,1 and 6,2.

To carry out an appraisal of this design concept, the designer 'describes' his scheme to the machine as outlined in the following sub-section.

<u>Input Format</u> When the programme is called up (see Table 1) the computer prints the program name, the date and the time. It then asks the question.

ARE YOUR UNITS IN METRIC? 0/1
?

and waits for a reply to be typed on the key-board by the designer. In this case the units are imperial and so the designer, in accordance with convention, types 'O' to indicate "No". (Throughout Table 1 the responses of the designer have been under-lined for ease of interpretation.) The current version of PACE 1 operates in imperial units and produces the output in imperial units but, as implied by the first question, the machine will accept a metric input; a fully converted program is in the course of being written.

The input, as can be seen from Table 1, is in five sections - General Information, Geom-etric Information, Site Information, Construc-tional Information and Activity Information. These are dealt with in turn in the following sub-sections.

General Information: In this section the designer specifies the building type, the number of occupants, the location of the site and the height of the site above sea level. This allows the computer to access stored data on pattern of occupancy, recommended environmental standards and climate.

```
READY
RUNBIG

PACOBJ     09:25  SYSED TUE21ST SEP 1971


IS DATA TO BE READ FROM A FILE        0/1
 ?1

WHAT IS YOUR JOB NAME
 ?EXAMPLE

ARE YOUR LENGTHS IN METRIC UNITS        0/1
 ?0

******
INPUT
EXAMPLE
******
GENERAL INFORMATION
-----------------------------
WHAT IS YOUR BUILDING TYPE?
 1=SCHOOL
2=HOSPITAL
3=OFFICE
4=HOUSE
5=FACTORY
6=FACTORY(SHIFTS)
 ?1

WHAT IS TOTAL OCCUPANCY OF SCHEME
 ?1000

WHAT IS LOCATION OF SITE
 1=SCOTLAND
2=MIDLANDS
3=SOUTH
 ?1

WHAT IS THE ALTITUDE TO THE NEAREST 50 FEET
 ?50

GEOMETRICAL INFORMATION
------------------------
TYPE COMPONENT NO. AND ELEMENT NO. ON ONE LINE
AND ON NEXT LINE 6 COORDINATES
DO THIS FOR ALL ELEMENTS - FINISH WITH TWO ZEROS
 ?1,1

 ?160,40,0,320,200,10

 ?2,1

 ?160,40,10,320,200,20

 ?3,1

 ?40,120,0,160,200,10

 ?4,1

 ?40,200,10,120,230,20

 ?5,1

 ?40,230,0,120,360,20

 ?6,1

 ?230,230,0,320,230,10

 ?6,2

 ?200,230,0,320,320,10

 ?0,0
WHAT IS THE NOMINAL FLOOR TO FLOOR HEIGHT
 ?10
WHAT IS YOUR GROUND FLOOR LEVEL
 ?0
WHAT IS THE ANGLE BETWEEN THE Y AXIS AND TRUE NORTH
 ?20
****
SITE INFORMATION
----------------
WHAT ARE YOUR X AND Y SITE LIMITS
 ?400,400
HOW MANY ROWS AND COLUMNS HAVE YOU IN YOUR SITE MATRIX
 ?2,2
TYPE IN SITE VALUES FOR EACH ROW
ROW          1
 ?2,5

ROW          2
 ?3,1
```

Table 1

```
*****
CONSTRUCTIONAL INFORMATION
--------------------------
25 PERCENT GLAZING ON 4 WALLS, NO GLAZING ON ROOF AND
MEDIUM STANDARD INSULATION HAS BEEN ASSUMED
DO YOU WISH TO INPUT PARTICULAR GLAZING AND INSULATION
VALUES FOR ANY OF THE ELEMENTS        0/1
 ?1

TYPE COMPONENT NO. AND ELEMENT NO. ON ONE LINE
THEN TYPE IN PROPORTION GLAZING ON EACH OF THE 4 FACES
AND ROOF THEN SIMILARLY FOR INSULATION + FLOOR
 1=LOW STANDARD INSULATION
 2=MEDIUM STANDARD INSULATION
 3=HIGH STANDARD INSULATION
FINISH WITH TWO ZEROS
 ?1,1

GLAZING DATA
 ?.2,.2,.2,.2,0

INSULATION DATA
 ?1,1,1,1,1,1

 ?2,1

GLAZING DATA
 ?.2,.2,.2,.2,0

INSULATION DATA
 ?1,1,1,1,1,1

 ?3,1

GLAZING DATA
 ?.2,.2,.2,.2,0

INSULATION DATA
 ?1,1,1,1,1,1

 ?4,1

GLAZING DATA
 ?.2,.2,.2,.2,0

INSULATION DATA
 ?1,1,1,1,1,1

 ?5,1

GLAZING DATA
 ?.3,.2,.2,.2,0

INSULATION DATA
 ?1,1,1,1,1,1

 ?6,1

GLAZING DATA
 ?.2,.2,.2,.2,1

INSULATION DATA
 ?1,1,1,1,1,1

 ?6,2

GLAZING DATA
 ?.3,.2,.2,.2,0

INSULATION DATA
 ?1,1,1,1,1,1

 ?0,0

*****
ACTIVITY DATA
-------------
TYPE ASSOCIATION OF COMPONENT WITH EACH
OF HIGHER NO.
COMPONENT          1
 ?3,5,2,7,8

COMPONENT          2
 ?1,7,6,2

COMPONENT          3
 ?5,2,7

COMPONENT          4
 ?3,3

COMPONENT          5
 ?1
```

Table 1 (cont'd)

Geometrical Information: The geometrical configuration of the scheme is input by typing in the coordinates of the two opposing vertices of each spatial element. The response 1,1 labels the element and the response 160,40,0,320,200,10 gives the x, y and z coordinates of the vertex nearest and furthest from the origin, as can be seen by reference to Figure 3: this simple input statement uniquely defines the size, shape and location of Component 1. The elements are entered in any order and the response 0,0 typed to indicate that this part of the input is complete. Additionally the computer requests information on the floor to floor height and the ground floor level (in relation to z = 0). The orientation of the scheme is input by giving the angle between the y-axis and the north point (Figure 4). It should be noted that no modular constraint is imposed by this form of input, unless specifically applied.

Site Information: The mechanism for describing the site to the computer is that of imagining a rectilinear grid placed over the site with a numerical value attached to each cell in the grid (see Figure 4). After inputting the overall dimensions of the site, the designer can specify how course or fine this grid is: for a uniform site the designer may specify, say, 2 rows and 2 columns; for a varied site he may specify a 20 x 30 grid. The actual values attached to the cells may be on any scale (in this case 0-10) and are input a row at a time, starting with the row adjacent and parallel to the x-axis (see Figure 3). It should be noted that the size of the site cells need bear no relation to the size of the spatial blocks input under Geometrical Information.

Constructional Information: This section of input allows information to be given about the proportion of glazing and the insulation properties of each face of each spatial element. If the designer wishes to waive this option, the machine will assume values on his behalf; thus if he answers 0 to the initial question in this section of the input the machine will inform him that, in this case, it will assume 25% area of glazing on all vertical surfaces, no glazing on horizontal surfaces, and medium standard insulation throughout. If he elects to input his own data, machine asks in turn for the glazing data and the insulation data for each element. A glazing data response of .2, .3, .4, .5, 0 indicates 20% glazing on the vertical surface nearest the x-axis, 30% on the vertical surface nearest the y-axis, 40% on the vertical surface furthest from the x-axis, 50% on the vertical surface furthest from the y-axis and zero glazing on the upper horizontal surface. An insulation data response of 2,2,2,2,1,3 indicates medium standard insulation on all four vertical surfaces (dealt with in the above order), low standard insulation on the upper horizontal surface and high standard insulation on the lower horizontal surface. It is important to note that the machine will take full account of horizontal and vertical interfaces between spatial elements and components; thus if component three abutts component one, the proportion of glazing on the relevant surface of component one will relate only to the un-adjoined surface.

Activity Information: The final section of input is the relationship matrix shown in Figure 2. The numerical values are typed in for each component in turn as can be seen by reference to Figure 2 and Table 1.

Output Format Table 2 gives the output format as it is typed by the computer. The output is in four sections - costs, spatial performance, environmental performance and activity performance. Before dealing with each section in turn, it is necessary to explain the three columns of numerical values. The first column headed "VALUE" is the absolute value measured by the computer in the appropriate units; the second column headed "UNIT VALUE" is a standardised measure, intended to be independent of size of the scheme; the third column headed "MEAN" is the mean unit value of all previously computed schemes of similar building type - of which more will be said later.

Costs: This first section of output deals with capital and running costs; the first column is in pounds sterling, the second and third column in pounds sterling per occupant. Capital cost and maintenance cost are computed by taking off quantities of floor area and surface area and multiplying by unit cost data held in file under each building type. Lighting and heating costs are obtained by multiplying the loads (described later) by the current unit energy costs which are held in file. When the designer chooses his fuel type, the hot water costs,

```
*****
OUTPUT
EXAMPLE
****
                                       VALUE     UNIT VALUE    MEAN
---------------------------------------------------------------------
COSTS
------
CAPITAL COST                    $    432000.     432.0000    529.7000
MAINTENANCE COST/ANNUM          $      2951.       2.9512      3.3730
LIGHTING COST/ANNUM             $       387.       0.3872      0.5262
HEATING COST /ANNUM
------------------
ELECTRICITY                     $      4139.       4.1386      5.4729
OFF-PEAK ELECTRICITY            $      3016.       3.0163      3.9939
GAS                             $      1473.       1.4731      1.9458
OIL                             $      1179.       1.1795      1.5596
ANTHRACITE                      $      1030.       1.0302      1.4226
DISTRICT HEATING                $      1439.       1.4380      1.9925
WHICH ENERGY DO YOU WANT        1-6
 ?3

HOT WATER COST/ANNUM            $       384.       0.3841      0.3840
TOTAL RUNNING COST/ANNUM        $      5995.       5.9955      6.3045
------------------------------------------------------------
SPATIAL PERFORMANCE
--------------------
SITE UTILIZATION
                                                   0.3000      0.3309
SITE VALUE
                                                   4.0000      2.7250
PLOT RATIO
                                                   1.3000      1.2593
PLAN COMPACTNESS
                                                   0.5118      0.7131
MASS COMPACTNESS
                                                   0.4028      0.4273
-------------------------------------------------------
ENVIRONMENTAL PERFORMANCE
--------------------------
X-SECT AREA RAIN WATER PIPE        544.      0.5440      0.4935
PERMANENT ART. LIGHT. REQD.      23600.     23.6000     35.8750
MECHANICAL VENTILATION REQD     472000.     472.         730.
HEAT LOSS/UNIT AREA                        23621.      27402.
TOTAL WATER STORAGE              10999.     10.9000     13.3333
SIZE OF HOT WATER CLORIFIER       1000.      1.0000      1.3333
SIZE OF BOILER                 4451615.   4451.6155   5754.3615
FOR HOW MANY COMPONENTS
DO YOU WISH HEAT GAIN/LOSS DIAGOSTICS
 ?2

WHICH COMPONENTS
 ?1,6

                        83371440.1
                        87194511.1
                        74965774.1
                        58549744.5
                        36146474.2
                       -17325555.5
                       -17146415.5
                       -16724967.5
                        36341946.9
                        43191997.7
                        71951713.3
                        73817386.5


                        39519212.7
                        32173343.7
                        35324742.1
                        27393938.9
                        17661246.1
                        -5622789.1
                        -5441329.1
                        -4765397.1
                        14627762.1
                        24271176.5
                        34722313.3
                        37934794.9

---------------------------------------------------------
ACTIVITY PERFORMANCE
--------------------
MATRIX OF DIVERGENCES FROM MEAN
        1      2      3      4      5
  2  -.94
  3  -.14   -.31
  4  -.43   0.37   -.41
  5  3.19   1.12   -.64   -.74
  6  9.53   -.53   1.01   -.26   -.74
STANDARD DEVIATION                                   9.39        0.28
DO YOU WISH TO CHANGE INPUT INFORMATION             0/1
 ?0

DO YOU WISH TO UPDATE FILE OF MEANS          0/1
 ?0

STOP
```

and hence total costs, can be output.

Spatial Performance: Spatial performance is measured by a set of ratio values, hence the fact that entries do not appear in the first column. Site utilisation is computed according to the traditional definition (i.e. the total floor area of the scheme divided by the site area), as is plot ratio (i.e. the total floor area of the scheme divided by the ground floor area). Plan and mass compactness are computed on definitions developed by the Building Performance Research Unit: plan compactness is defined as the inverse ratio of the plan perimeter to the circumference of a circle of equal area; mass compactness is defined as the inverse ratio of the surface area of the mass to the surface area of a hemisphere of equal volume. The remaining measure – site value – involves the numerical quantities attached to the cells in the site grid and is defined as the ratio of the average value of the cells covered by the scheme to the average value of all the cells on the site.

Environmental Performance: As opposed to actually measuring the environmental characteristics of the scheme, this section of the output essentially gives the sizing of plant which will result in adequate environmental conditions. The storm water piping is sized by taking account of roof area and stored information on maximum storm water precipitation. The area requiring permanent artificial lighting and the volume requiring mechanical ventilation are obtained by computing the floor area and volume of the central core a predefined distance from the outside glazed surfaces of the scheme. Sizing of the total water storage and of the hot water calorifier is achieved by applying the design recommendations in the IHVE guide, using stored constants and the information on the number of occupants which was output under General Information. Heat loss and gain are computed per hour for each spatial component and are based on

(a) stored information on hours of occupancy (which depends on building type);

(b) stored information on air change rates (dependent on building type);

(c) stored information on transmittance

coefficients (dependent on standard of insulation and proportion of glazing);

(d) stored information on indoor/outdoor monthly temperature differences (dependent on site location and altitude);

(e) stored information on solar gain factors (dependent on orientation of the four vertical surfaces, and area of glazing on each);

(f) heat gains from the occupants (dependent on number of occupants);

(g) lighting gains (dependent on volume of core and glazed periphery);

The boiler is sized on the basis of the maximum computed hourly heat loss. Apart from outputting the resultant heat loss per unit area, the program gives the designer the option of obtaining the month by month heat losses and gains for any number of individual spatial components; in the example given the losses and gains (gains identified by a negative sign), January through to December, have been output for components one and six. Throughout this section, with the exception of heat loss/unit area, the unit values, i.e. the values in column two of the output are obtained by dividing the absolute values in the first column by the number of occupants in the scheme.

Activity Performance: The final section of output provides measures of the degree to which the relationships input under Activity Information are satisfied by the proposed scheme. If the relationship measure in Figure 2, between components i and j is A_{ij} and the distance between these components in the proposed scheme is d_{ij}, then ideally A_{ij} should be inversely proportional to d_{ij}, i.e. the greater the relationship between two components, the closer together they should be. In other words, ideally $A_{ij}d_{ij} = k$, a constant. Since the magnitude of this constant will vary from scheme to scheme depending on the size of the scheme and the scale of relationship values, a standardisation is performed by computing the set of values

$$\frac{A_{ij}d_{ij} - \text{mean } A_{ij}d_{ij}}{\text{mean } A_{ij}d_{ij}}$$

and these are printed out in the matrix shown in the final section of Table 2. Since the ideal situation is represented by zero values in the matrix, it follows that a high positive value, as between components one and five, indicates that these two components have been located too far apart; a high negative value, as between components two and three, indicates that these two components have been located too closely together. To summarise this matrix, the standard deviation of the values in it are computed and output.

Three questions are asked by the computer at the conclusion of the output. The first invites the designer to change any of the input - the location of any component, the orientation, the areas of glazing, etc. The second question is applicable when the designer is satisfied that the scheme is a good one; by answering <u>1</u>, all the unit values relevant to his scheme are used to modify, i.e. upgrade, the mean values stored from all previous schemes of similar building type. On subsequent use of the program, therefore, the mean values in column three of the output will be the most current available. The third question gives the option of obtaining perspective views of the scheme; if the designer answers <u>1</u>, the computer produces paper-tape which, when fed into a graph plotter will cause eight perspective views to be drawn (Figure 5).

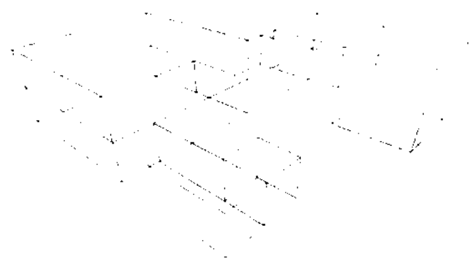

Figure 5

<u>Use</u> There are several ways in which the package can be used. The most obvious use is for the iterative modification of a design scheme to satisfy a particular brief. Another use is to compare alternative layout design strategies - linear, lattice, exocentric, etc. (4). A third use is the generation of the causal relationships between design variables : by systematically varying the input, keeping all variables constant except the ones under investigation, relationships such as that illustrated in Figure 6 between compactness and running costs, can be established from

the output.

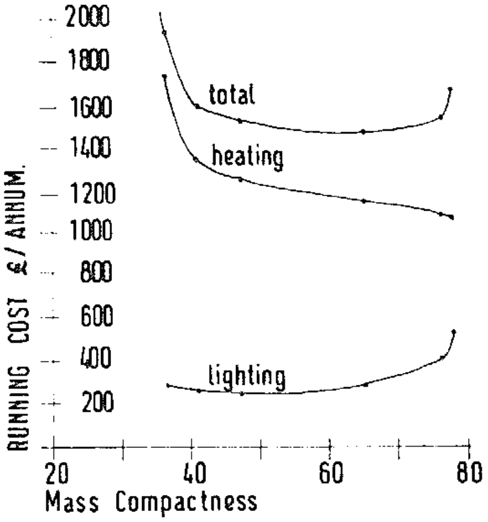

Figure 6

Future Developments

Developments and modifications currently in hand include

(a) amortisation of capital costs (based on an input of anticipated design life) to give an output of costs-in-use;

(b) a version working entirely in S.I. units;

(c) output of cut and fill based on an input of site ordinance levels;

(d) output of sun incidence on each face of each component, taking account of obscuring masses;

(e) a fourth column in the output giving the standard deviation of cost and performance data from previous schemes;

(f) a graphic version using a Tektronix 4010 direct view storage tube terminal;

(g) packages specific to schools, hospitals, housing;

(h) two further packages, PACE 2 and PACE 3, relevant to the next two more detailed stages in design

(i) an auto-modifying version of PACE 1.

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