PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Systems Health Building

R. H. Goodman

Phil. Trans. R. Soc. Lond. A 1972 **272**, 611-619
doi: 10.1098/rsta.1972.0068

Phil. Trans. R. Soc. Lond. A. **272**, 611–619 (1972) [611]
Printed in Great Britain

Systems health building

By R. H. Goodman
Department of Health and Social Security, Alexander Fleming House, Elephant and Castle, London, S.E. 1

The purpose of this paper is not to produce an erudite exposition of the planning and construction of hospitals but to demonstrate the direction in which technology (and in this context, design technology rather than building technology) is moving taking as an example possibly the most complex of all building types, namely hospitals.

The work described is probably the most advanced in the field of computer-aided design currently in progress and it is not wholly accidental that this work is taking place at the D.H.S.S. The fact that there is a large centrally monitored on-going programme of building, that relations between the Department and the regional authorities are good and that a fund of research and development data has been built up over the years, all contribute to making the situation ripe for this technology. It should be stressed that this programme is the result of a multi-disciplinary team approach to the problem – multi-disciplinary in the sense of including not only building professions but also the planning doctors, nurses, statisticians and others that form part of this team.

The planning of hospitals has all the problems that are inherent in the planning of other building types, except that they tend to be magnified; that is, the relationships between the functioning parts of the building are complex the environmental services are critical and changes in technical (in our case medical and nursing) management techniques are considerable and unpredictable. These are the problems that are faced in the context of an apparently irreducable time normally taken in the design, production and construction stages of these buildings, assuming that we continue to use all of the traditional techniques.

It has long been felt that hospitals were unique buildings serving a unique collection of clients and a unique community, that there is something esoteric in their design that can only be understood by specialists, and that no two problems were the same. A series of research and development projects carried out by the D.H.S.S. attempted to rationalize some of these beliefs and attempted to simplify the apparently conflicting requirements of the various parts of the hospitals and the various users. In building terms this meant attempts to reduce the construction to the lowest common denominator compatible with housing dissimilar functions, to identify the common functional elements particularly those which were inter-departmental and to go further into the rationalization of the construction in an attempt to find a system of modular or dimensional coordination.

A first project at Walton Hospital, Liverpool, managed to accommodate a variety of differently functioning departments within the same structural envelope which in itself allowed for the high degree of environmental services integration. The building was industrialized, pre-cast and capable of rapid erection. Further studies culminated in a design for Greenwich District Hospital which was completely air conditioned and has a sophisticated system of environmental control. The structure is totally pre-cast, highly dimensionally disciplined and at the same time houses all the departments of a normal general hospital. Its structural components having been reduced to four basic elements, the columns, the beams, the slabs and the fascia panels which were constant throughout the entire building in fact gave it its architectural character. At the same time certain key elements to the management of the hospital were identified in terms of movement and communications; and considerable studies were done to measure and monitor these movements.

Following this project two identical hospitals were built at Bury St Edmunds and Frimley utilizing the experience of industrialized building, repetitive structures and communication systems confirmed at Greenwich. Although the buildings were exercises in economical building their real value was not as cheap buildings but in the fact that two identical buildings were constructed for different clients serving communities some 300 km apart. This was probably the watershed in standardization in that the clients, traditionally highly individual customers, were prepared to accept a standard solution providing of course that the standard solution was sufficiently flexible for their needs.

Concurrently with these exercises the Department was engaged in the rationalization of the various structural and constructional components of health building not only in their dimensions and design but in the processes by which this information passed from designer to manufacturer to constructor The communication of information remains one of the major problems within the building industry and seems very susceptible to a systems analysis approach. The Cubith† method consists of six basic subsystems within a total system and comprise briefing, designing, production material, construction, commissioning and an evaluation subsystem. These subsystems presume the construction of a data bank consisting of a series of data bases which will be constantly updated. Our present efforts will concentrate on three major subsystems governing the production material and construction processes and will apply these to the harness projects. At the same time work was started in an attempt to relate this systematic approach to a.d.p. techniques taking the premise that it was possible to use systems without computers but not computers without systems.

At this stage the Department extended its research and development effort into an exercise in the feasibility of planning standardization in the context of a systems approach to the briefing, planning and construction process. Preliminary work had already been carried out into the standardization of two departments of a hospital namely wards and maternity with only limited success. However, if as seemed likely the 'climate' was right for the acceptance of standardization, how could this possibly be achieved bearing in mind that to be fully effective it should be nationally acceptable?

It was hypothesized that if the communication system at the hospital was the key to its planning and if its communication system could be 'generically' typed then it would be possible to build up a range of hospitals with identifiable, and measurable communication patterns, together with the standardized planning components. Based on researches on earlier projects mentioned the likely communications (or harness) shapes seemed to be the ring main, the T, the H, the L and the linear pattern each of these having of course different communication characteristics (see figure 1). Matrices were developed to determine the ideal relationship of the various departments of the hospital at the varying scales of size. Some of these relationships could be variable and size-dependent such as the relationship between stores and wards but some were virtually absolute such as distances between surgical wards and theatres. At the same time

† Coordinated use of building industrial technology for health.

feasibility studies were carried out to determine whether a structural envelope was possible for all parts of these hospitals using the expertise already available from the Walton and Greenwich studies. Structural and economic investigations coupled with the decision not to generally apply full environmental control to the building led to the final adoption of a 15.3 m

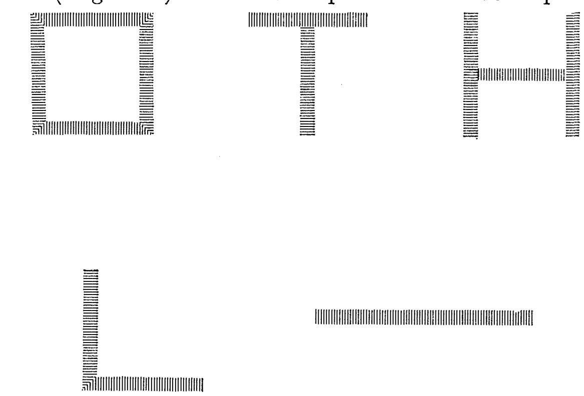

FIGURE 1. Harness generic shapes.

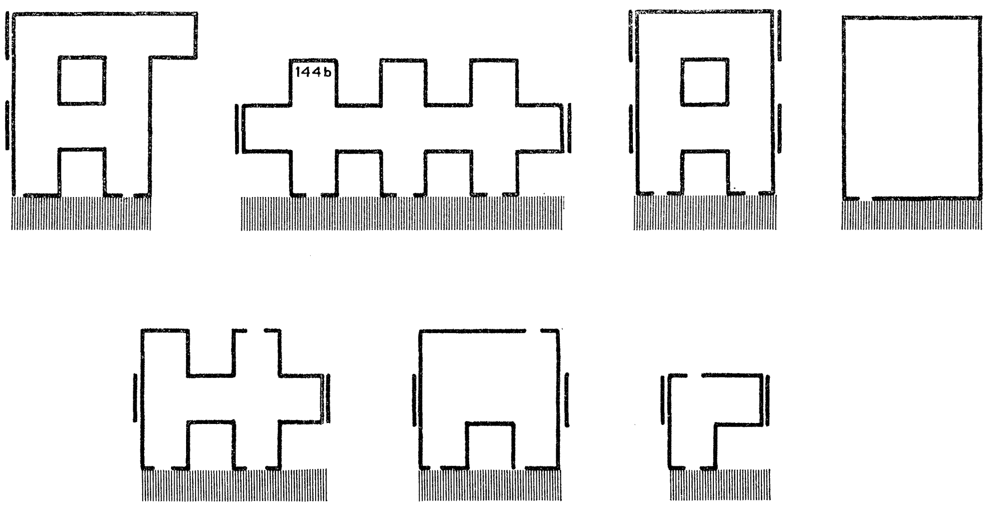

FIGURE 2. Typical standard profiles of hospital departments.

span structure with a secondary dimension of 5.1 m; limiting the height of the buildings to four storeys. This seemed to provide the right balance between economic structure and the communication requirements of the hospital. After a series of studies in cellular growth patterns of buildings it was decided to use a chequer board pattern for a development for all the departments of the hospital linked to the harness zone at one end and extended outward in preferential series of profiles (see figure 2).

At this stage of the development the Department asked for and received the assistance of a number of regional hospital board design teams in the preparation initially of standardized

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

operational policies and later in the actual design of the specialized hospital departments. The standard operational policies, which were designed to be nationally applicable, were used as the guidance for these multi-disciplinary design teams set up in the participating regional hospital boards. It was the task of these teams to design a range of incrementally sized departments that could cope with the district general hospitals currently being designed up and down the country and in conformation with the draft operational policies already agreed. A considerable amount of expertise already existed in regional hospital boards in different building types and teams which had specialized knowledge were selected for the appropriate hospital department.

Although the systems side of this exercise was already committed to a.d.p., exercises were now carried out to see whether this highly dimensionally disciplined type of development was applicable to computer-aided design techniques and work was commissioned with Applied Research of Cambridge Ltd to this end. It seemed that this form of planning was in effect playing a game of three-dimensional chess which could equally well be played by the use of a computer, assuming that the computer could be programmed to know the rules of the game. The large integrated system which was necessary could only be justifiable if there were some form of coordinated loading methods in order to realize the full economic potential in a way that manual methods cannot. And also this system could only be commissioned by a large organization such as the D.H.S.S. although it could be subsequently and profitably used by regional hospital boards and private consultants.

The work soon divided itself into two separate packages, the hospital assembly program (h.a.p.) and the simulated hospital evaluation program (s.h.e.p.) both of these programs being highly dependent on the logical principles of the 'harness' concept itself and they are as designed neither feasible nor viable in a more general context.

The h.a.p. process is essentially a spatial allocation tool with some very significant features; it depends on the designers' choice of harness shape for the development: this decision takes out of the machine sphere any dubious or bad judgements, and allows the designer a great deal of control over the outcome. It manipulates real building blocks – the harness departments which have known contents and rules of assembly. The traffic relationships between departments and hospitals in this context are already relatively well understood and are not subjected to judgements but are collectable data and described in the matrices. The program allows the design team many degrees of manipulation over the development control plan varying from the fully automated to the non-automated (hand-cranked) solution. Although the design team can input a complete hospital manually the advantage of the computer assembly seems to be in the ability to rapidly evaluate the series of alternatives on one site or a series of alternatives on a varying number of sites and to produce the absolute or comparative economic solution. It can execute these tasks rapidly and efficiently and it can also make available the alternatives for these evaluations (see figure 3). The program attempts to arrive at a simultaneous absolute solution of the problem rather than a sequential placement or component swapping solution employed by more generalized methods. Even within the disciplines of the harness concept however the automatic simultaneous solution to the problem is a very large computing task and therefore the automatic assembly process is split into two separate stages with further design manipulation available at the intermediate point. These two stages are first the clustering and secondly the positioning of spaces. As a response to the in-put of the generic harness the site area in relation to the route is split into zones on each level of development. The primary stage is the automatic process which tests exhaustively the allocation of various clusters of departments and of the zones and the results and arrangements giving a minimum estimated total circulation of the whole hospital. The second stage explores the actual department fitting problems within each clustering zone. This system takes account of internal relationships of departments in the group, relationship of groups of departments in the remainder of the hospital and the spatial fitting problems of the departments of the groups themselves both horizontally and vertically. The outcome of this second stage is a layout plan of the whole hospital which is displayed – having been obtained from manipulation by the design team on grounds

```
EEEEEE         GGGGGGGGGGGG
EEEEEE         GGGGGGGGGGGG
EEEEEE         GGGGGGGGGGGG
   EEE   FFF   GGG   GGG   HHH         JJJJJJJJJ   KKK
   EEE   FFF   GGG   GGG   HHH         JJJJJJJJJ   KKK
   EEE   FFF   GGG   GGG   HHH         JJJJJJJJJ   KKK
EEEEEEFFFFFFFFFGGGGGGGGGGGGHHHHHHIIIIIIJJJJJJJJJKKKKKK
EEEEEEFFFFFFFFFGGGGGGGGGGGGHHHHHHIIIIIIJJJJJJJJJKKKKKK
EEEEEEFFFFFFFFFGGGGGGGGGGGGHHHHHHIIIIIIJJJJJJJJJKKKKKK
   EEE   FFF   GGG   GGG   HHH   III   JJJ   JJJ   KKK
   EEE   FFF   GGG   GGG   HHH   III   JJJ   JJJ   KKK
   EEE   FFF   GGG   GGG   HHH   III   JJJ   JJJ   KKK
******************************************************
******************************************************
         QQQQQQQQQ   PPP   OOO   OOO   NNN   MMM   KKK
         QQQQQQQQQ   PPP   OOO   OOO   NNN   MMM   KKK
         QQQQQQQQQ   PPP   OOO   OOO   NNN   MMM   KKK
RRR      QQQQQQQQQ↑↑↑PPPOOOOOOOOOOOOOOONNNNNMMMMMKKKKK
RRR      QQQQQQQQQ↑↑↑PPPOOOOOOOOOOOOOOONNNNNMMMMMKKKKK
RRR      QQQQQQQQQ↑↑↑PPPOOOOOOOOOOOOOOONNNNNMMMMMKKKKK
         QQQ   QQQ   PPP   OOO   OOO         MMM   KKK
         QQQ   QQQ   PPP   OOO   OOO         MMM   KKK
         QQQ   QQQ   PPP   OOO   OOO         MMM   KKK
      QQQQQQ   ↑↑↑
      QQQQQQ   ↑↑↑
      QQQQQQ   ↑↑↑
```

Figure 3. Computer output showing part of development control plan.

of personal choice or for reasons of architectural massing – and which then may subsequently be stored for further analysis by the s.h.e.p. This h.a.p. program has stressed firstly the role of the design team in a development control plan (d.c.p.) process and secondly the relatively rapid response required. The system has always been considered as an interactive design team-computer task. Recently definite modes of working have been put forward; initially it was considered that conventional teletypes in various parts of the country would be a suitable mode of working and the system was originally written with this in mind. However, as the pattern of D.H.S.S. systems approach to hospital building became clarified actual modes of working have been implemented. Even now the use of true interactive graphics terminals is not seen as an absolute necessity and this economic manner of thinking has limited much of the program writing and the size of the programs have been held down to remain competitive in the Atlas time sharing environment.

One of the most significant features of the harness hospital d.c.p. systems is the ability to translate from the image of the building displayed at the end of the h.a.p. process (which is solely a demonstration of disposition of parts) into a realistic simulation of much of the hospital which would result from this particular assembly (figure 4). The vehicle for this is the building representation which is manipulated by the programs to give indicators of design performance of the comparative processes.

The building representation is translated into several forms suitable for the various evaluative tasks required. In the harness concept there are two planning modules; 15 m square basic planning modules which can be subdivided into 5 m square dimensional modules these being the basis for the evaluative operations. In the course of h.a.p. process the hospital is held at the level of 15 m square module to economize on space.

Before the s.h.e.p. process conversion is required to describe it at the 5 m square module level, simultaneously this conversion creates other descriptions such as height description and the description of unfilled structural areas. Also a compact description of the harness. This mechanism is used more because of computing necessity rather than the direct need for running the program.

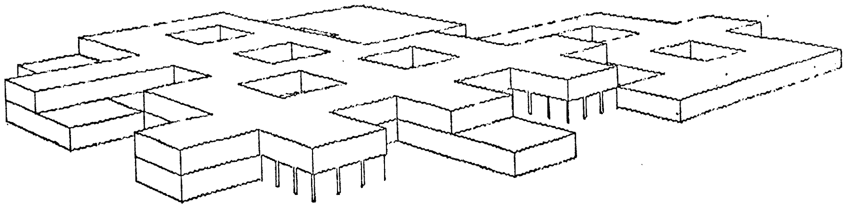

FIGURE 4. Computer drawn perspective of project produced by hospital assembly program.

```
       +A5+A7+A5+A7+A5+A7+A5+A7+A5+A7+A5+A7+
       |  |  |  |  |  |  |  |  |  |  |  |  |
       |  |  |  |  |  |  |  |  |  |  |  |  |
       A2 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A3
       |  |  |  |  |  |  |  |  |  |  |  |  |
       |  |  |  |  |  |  |  |  |  |  |  |  |
       +A4+A6+A4+A7+A5+A7+A4+A6+A4+A7+A5+A7+A5+A5+A5+
       A7        A7       A7        A7       A7        A7
       +---A1----+        +---A1----+        +---A1----+
       A5        A5       A5        A5       A5        A5
       +---A1----+        +---A1----+        +---A1----+
       A7        A7       A7        A7       A7        A7
7+A5+A7+A4+A6+A4+A7+A5+A7+A4+A6+A4+A7+A5+A7+A4+A6+A4+A7+A5+A7+A5+A7+A5+A7+A5+A7
 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1
 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
7+A5+A7+A4+A6+A4+A7+A5+A7+A4+A6+A4+A7+A5+A7+A4+A6+A4+A7+A5+A7+A4+A6+A4+A7+A5+A7
       A7        A7       A7        A7       A7        A7       A7        A7
       +---A1----+        +---A1----+        +---A1----+        +---A1----+
       A5        A5       A5        A5       A5        A5       A5        A5
       +---A1----+        +---A1----+        +---A1----+        +---A1----+
       A7        A7       A7        A7       A7        A7       A7        A7
```

FIGURE 5. Computer output showing location of structural components.

The simulated hospital evaluation program (s.h.e.p.) is used for comparative analysis for alternative hospital plans and much of the detail desired can be considered in sealed 'packages'. However, the comparative analysis is concerned in great detail with those parts of the hospitals which do vary according to choice of assembly. Thus the s.h.e.p. are involved in simulating the variations in circulation, cladding, environmental performance, energy requirements, the harness itself, site usage, site works and structure. Logically the manner in which the evaluative processes operate is definable as two separate steps, automatic design and evaluation of the simulated hospital. The concept of automatic design is significant, it is the process by which relatively small amounts of information held in the building representation 'fleshes out' the component detail of the particular building in question, internal to the machine by depending on the automatic inference of details according to their context with the whole d.c.p. In other words the machines 'know' the inherent logic of the building method and is able to act on it to set up its own basis for building evaluations. These evaluations may take the form of 'taking off' the components identified or calculations in the environment or energy load in the building. As these evaluation results are produced by the machine a synopsis can automatically be retained on a special file which can be integrated at a future time to act as a comparative measure of hospital performance. In addition to providing an absolutely accurate basis of hospital costing by unit components these mechanisms simultaneously locate all those components within the shell and structure (see figure 5). This is significant in the production documentation process and it is possible to hand over such items of information for automatic inclusion within the production documentation system. And it seems clear that A.R.C.'s output of location information of d.c.p. will satisfactorily form the basis for the collation of detailed information on separate departmental information into the 'whole' project file.

The system developed for production documentation is based on the design conventions of a range of dimensionally coordinated components available from the manufacturers data base and developed for the harness programme. The production documentation stage should carry sufficient information to obtain tenders and build the required buildings. This information will include the component schedule and sub-bills of quantities, production drawings (in the various scales and amount of detail required) and junction schedules.

Nevertheless, the programs necessary to carry out this work must be part of a robust and non-programmer orientated system capable of handling large volumes of data, for use by professionals in the building world rather than the computer operatives. The intention initially is that the production documentation should be provided as a bureau service operated by the D.H.S.S. to process the data required for any harness scheme which is to be built by the r.h.b. or private consultants within the harness program and for this purpose an input to the system makes use of a specially developed take off language. The process in filing and retrieval of data is performed from the Atlas 2 computer at the C.A.D. Centre Cambridge. For the technically minded, these programs are written in systems assembly language (s.a.l.), a high level language incorporating some of the characteristics of Titan machine code and those of conventional high level languages, with the schedules being prepared on an ICL 1904 computer. However, provision is being made to transfer at a later date the whole system to this series of machine. Data is input to the system by means of a remote job entry terminal and data preparation is carried out initially at the D.H.S.S. using digitizers to digitize the pre-production drawings, in an off line mode. The output paper takes are fed into an Elliott 905 connected via a 4800 bits per second line to the Atlas in Cambridge. Check plots of the digitized data are fed back to London and output on a Tektronix 4002 direct view storage tube for visual checking by the operator and hard copy can also be obtained from this unit. When complete data sets have been filed and verified the user can request the output documents required and these can be produced either on a Calcomp drum plotter at D.H.S.S., linked by a 200 Baud line to the Atlas, or alternatively Atlas will produce an industry-compatible magnetic tape which can be fed into a micro plotter. Since Harness is based on a modular design concept, the same philosophy has been carried through to the storage and retrieval of data within the computer system, i.e. digitizing is only necessary for the initial data input, subsequently module data can be reused both in its original form or rotated as necessary to suit the configuration of a specific project and this includes mirror imaging. An essential element of this program is the ability to incorporate changes to update the project files to meet the evolving needs of the program, or changes in medical and nursing techniques. This updating of the module data can either be obtained by means of a digitizer using the same techniques as the initial input of data or by means of an interactive graphics terminal, operating in conjunction with the Elliott 905. This allows for full implications of any change to be visible in addition to providing any check on the planning implications. It can also provide a cost analysis. When the update is finally approved modifying data can be fed into the Atlas system to provide the latest version of the data-set for production use (see figure 6). However this does not necessarily eliminate the earlier Mk which in the case of certain changes in medical procedure may of necessity have to be available.

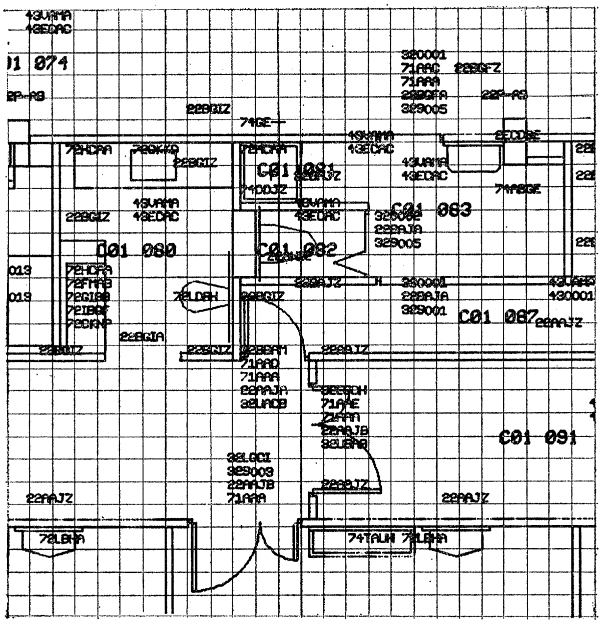

Figure 6. Part of computer drawn and coded layered drawing of standard department.

It is difficult in a short space of time to fully describe an extremely complex system of standards/a.d.p. orientated program of this magnitude, but already some of the potential benefits are becoming obvious. Much of the detail design data which project teams duplicate in unique situations has been eliminated and the best of the remaining data can be stored for retrieval and re-use. The previously lengthy and tedious process involved in producing development control plans can be reduced down to a minimum and more options can be evaluated than ever previously possible.

As the computer programs cover all the necessary information to construct the building including all environmental services, the problems of incompatability between structure, services and clinical planning can largely be eliminated. Because of the comparatively short timescale involved hospitals can be built using the latest possible 'Mk' of information at the same time allowing a closer monitoring of expenditure in the building program and this is likely to become a significant administrative tool. Sufficient work has now been done to confirm the validity of the systems health buildings approach although at this stage it would be premature to judge the effect of this on the hospital building programme. The first hospital to be built using these techniques will start its site works in 1972 (see figure 7). Already a large number of schemes are provisionally committed to this programme; the indications are that the total programme within the near future could well be several hundred million pounds.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Obviously this is only part of the total story, work is still to be done on the application of these techniques to regional and area planning, determining the relations of the medical needs of population and also on the later stages of commissioning and evaluation; the complete system will take some years to develop. It brings with it many problems; essentially this is design technology and it requires a reciprocal approach within the construction technology, particularly in the rapid assimilation and processing of this computer produced data, and this would assume the sophisticated management techniques within the building industry which have as

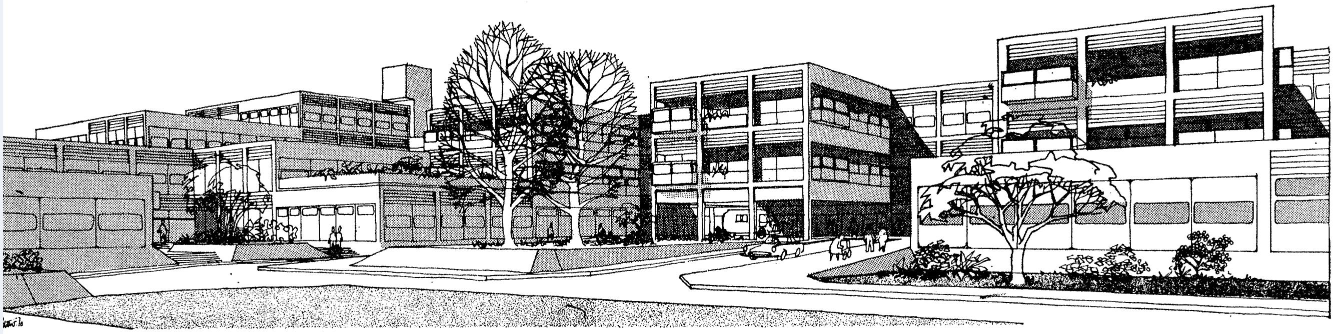

FIGURE 7. Perspective of first standard 'harness' hospital at Dudley, Worcestershire.

yet still to show themselves. It also raises considerable problems of inter-professional collaboration as these design techniques are total, the computer being unable to differentiate between one profession and another. It raises the question of whether the independent professional roles as at present exercised can continue. We are only now beginning to realize the implications on the education and training of the professionals concerned. To repeat the point made in the introduction to this paper the significance of this work is not in its application to the hospital building programme, but its application to the total building process. It seems evident that these techniques can be adapted to any large building programme either in this country or overseas with the significant effects on economics and time but not without an awareness of their considerable effect on the other technologies.