COMPUTER USES IN THE CONSTRUCTION INDUSTRY

COMPUTER USES IN THE CONSTRUCTION INDUSTRY

Prepared for the Department of
Industry, Trade and Commerce
By George Banz
Architect and Planning Consultant
Toronto, 1975

TABLE OF CONTENTS

Alternative approaches to computer use

Computers have been with us in ever-increasing numbers since the 1950s. Developed originally for military uses during the Second World War, they have gradually found their way into government offices and from there into industry and commerce. Today, it is difficult to visualize how governments, large banks, insurance companies or sales organizations could operate without computers, or how major airlines could deal with scheduling, reservations and ticket sales. Even researchers and other professionals such as engineers, economists, social scientists and doctors, have come to regard computers as indispensable tools.

On the other hand, when viewed in terms of computer use, the construction industry is underdeveloped. In general, computers are used by the largest and most enterprising firms only and even with them, they play no more than a marginal role. The reasons for the contrast are not difficult to pinpoint. For one thing, the construction industry uses few standardized components; buildings therefore continue to be custom designed even where standardization would make technical and economic sense. In addition, site work is organized on the basis of traditional crafts, rather than in a manner that utilizes semi-skilled labour such as might be used on a factory floor or assembly line. As a consequence innovation tends to be limited to the scope of individual crafts instead of being applied across the board. And true to another tradition, building design continues to be a professional activity that responds primarily to society's immediate needs, remaining relatively untouched by production and marketing considerations.

The strong ties to tradition that characterize the construction industry's operations are reinforced by the constant need for the people in it to deal with unexpected conditions and events. With design unrelated to market surveys, for example, user reaction to design innovation cannot be foreseen with any degree of certainty. Subsoil conditions are almost as unpredictable as weather conditions during construction. As a result, countless decisions are continually being made on the basis of minimal information. Inevitably, therefore, intuition plays a much larger role in design and construction than in other fields. A consequence of this is that the construction industry depends on an overlap of expertise and experience, whereas other industries favour fragmentation of all but senior management tasks.

This informal integration of specialized technical tasks makes it difficult to increase efficiency simply by introducing computers. One of the major functions of modern computers after all, that of integrating the operation of diverse parts of complex organizations, is dealt with effectively on a human level thanks to the organizational fragmentation of the construction industry. The creative interaction of experienced individuals, unaffected by organizational constraints, has both economic and social advantages. If computers are to play a positive role in construction, these advantages must not be sacrificed except in exchange for substantial alternative benefits. Experience suggests that greatest benefits are achieved if appropriate modes of computer application are developed within the industry rather than being transplanted from other operational environments.

Identification of tasks suitable for computer use

Not surprisingly, most successful computer applications to construction problems originated neither in the think tanks of computer manufacturers nor in universities, but with people active in the construction industry. Computers thus have proved their worth when they have been introduced in response to established needs. They have often failed when imposed on organizations by management responding to sales pressure or outside advice. As one of the pioneers in the application of quantitative methods to architecture pointed out years ago, acquiring a computer and then trying to find applications for it makes as little sense in a business, as buying a power drill and then looking for places to bore holes. Successful computer applications therefore originate more or less as follows:

1. A specific task is recognized as being repetitious and/or time-consuming.
2. A preliminary study establishes the suitability of computers for the task in question.
3. Different ways of using computers are analyzed and the alternative best suited to the task and its organizational environment is identified.

Further steps relate to problems of systems implementation and performance evaluation and will be mentioned later. The immediate aim is to describe instances where computers have helped solve problems in the planning, design, and administration of construction projects.

COMPUTERS IN PROJECT PLANNING

The pre-design stages of construction projects normally involve a multitude of rational, and therefore potentially computer-aided processes and decisions. If computers are not yet much in use in this area, it is largely because such planning has, in the absence of adequate hard data, traditionally been dealt with intuitively on the basis of past experience. In the process, emerging problems of the social and ecological impact of new projects on their environment have been almost entirely ignored. Even the economic viability of new projects, particularly in the long term, is too often taken for granted or decided, both from the points of view of the project proponents and of society, on the basis of an insufficient analysis of the underlying facts. In the planning of projects, therefore, the computer's role is not so much that of smoothing existing decision-making processes, but rather of introducing needed sophistication to a process that is inadequately based on facts.

The emerging uses of computers in the pre-design stages of projects offers a welcome opportunity to open up the planning process to the scrutiny of outsiders. It is not surprising, therefore, that the encouragement for developing computer-aided planning routines has come primarily from large-client organizations and from the public sector — both interested in clearly structured planning processes that allow the objective evaluation of all decisions. As in other applications, computerized processes have the important characteristic of rigidly following identifiable sequences of steps with the input known and all output available in the desired format. Two application areas, relating to location studies and economic analysis, are of particular interest. A third area, social impact studies, promises considerable future potential.

LOCATION STUDIES

There are instances in planning where the location of new facilities can be determined purely on the basis of computation. An example would be the optimum locating of warehouses that serve a national distribution network. In this case, general transportation and space requirements are known so the decision to locate a facility can be made by comparing costs such as land, municipal services, and taxes, as they relate to alternative sites. Similarly, potential shopping centre sites can be identified by analyzing the distribution of buying power in a region and relating it to available land that is accessible from existing or planned highways.

Most location studies, however, require the analysis of more complex factors and involve making value judgements at various points in the planning process. Although few decisions are made, in this case, on the basis of straight logic or calculations, computers can nevertheless be a valuable aid. Their most common application in location studies is in the processing of geocoded information and its graphic representation in the form of maps.

At their simplest, computer-generated maps present basic information that has been stored in

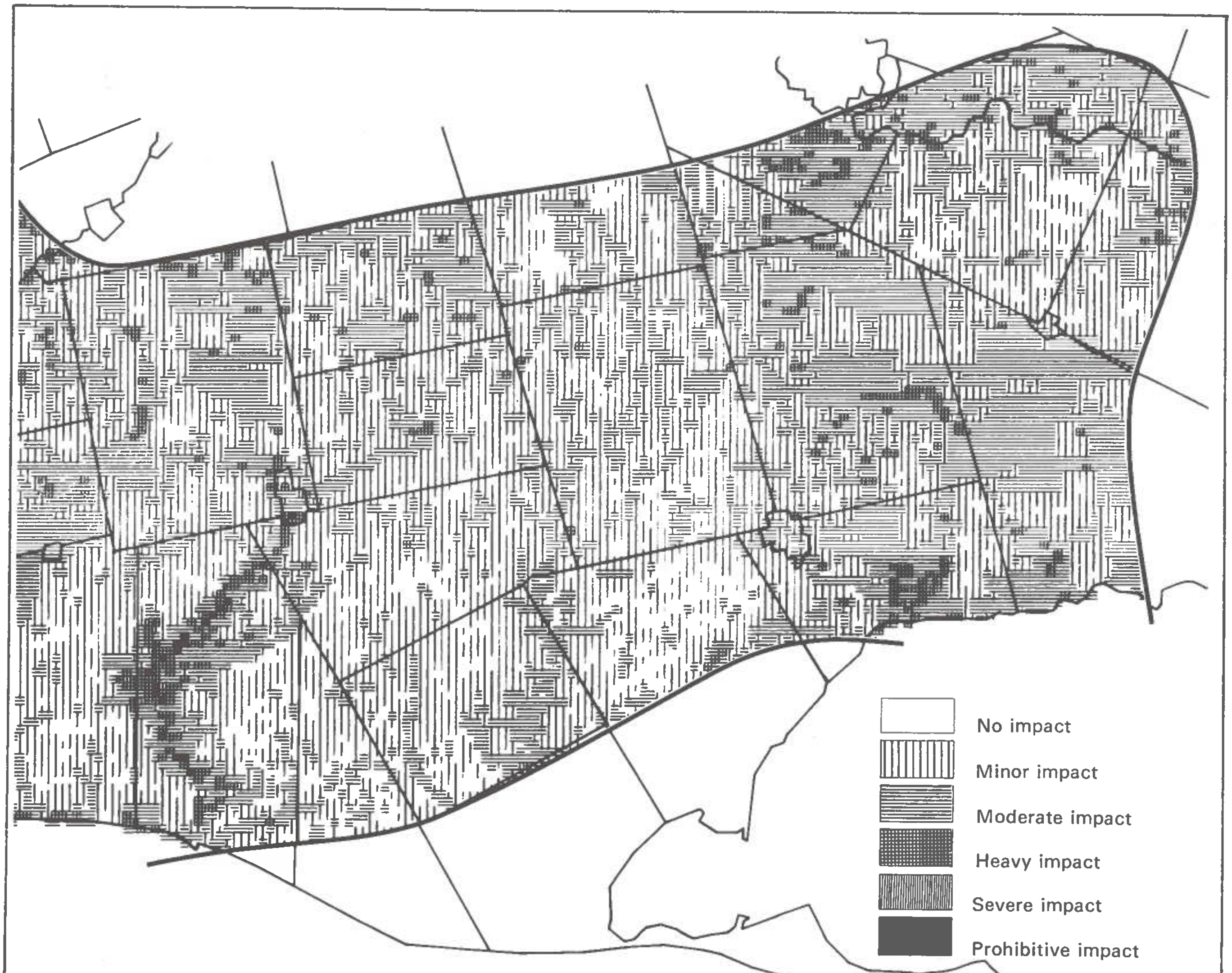


Fig. 1

Through overlays of selected base maps, computer-generated composite maps produced on a plotter can identify those parts of a site or region that satisfy specified conditions such as the probable ecological and visual impact of needed new facilities in alternative locations.

Source: James F. MacLaren Ltd.

digital form. They are custom-made "base maps" that may show such things as the quality and type of vegetation on the site, soil thickness, water table levels, and other data normally derived from aerial photographs. All such information is related to a square or rectangular grid pattern that is superimposed on the site. A computer can then be used to overlay selected base maps and, from the results, identify those parts of the site that satisfy specified conditions (Fig. 1).

This basic approach can be refined and extended in several directions. Through judicious programming, the computer can generate maps at a scale identical to that of standard topographical maps. This permits a direct comparison of grid data with information normally used in dealing with planning problems. Grid maps may be produced on a line printer, on a typewriter terminal, on a digital plotter, or on a television-like display screen. If a large-scale presentation is required, the computer may generate the maps in segments. Depending on the kind of computer equipment, maps may also be produced instantly in response to short typewritten commands, in black and white or in colour.

The information represented on computer-generated grid maps may concern environmental conditions of the kind described earlier. Alternatively, the computer may calculate such things as the likelihood of any of the grid cells on the site being exposed to the sun at any particular hour of any day and represent the results of the calculations in the form of a map, or it may calculate the parts of a site from which a nearby mountain or lake may be seen. The scale of such maps may be adjusted to the task at hand by focusing in on areas that are of particular interest.

Last but not least, computer-generated maps may not show existing conditions at all but present the results of mathematical simulations based on existing conditions. For example, hydrological models may be used to determine expected changes in water table levels as a consequence of planned interventions, with the results presented in the form of maps indicating the resulting changes in vegetation. Or the distribution of noise expected from the operation of a new airport may be superimposed on projected residential patterns to help evaluate alternative runway locations. In another kind of simulation, referred to as dynamic mapping, expected environmental change is represented visually by producing a series of maps that show successive stages of a development, (the evolution of new traffic patterns, for example) and display the process in the form of a film.

ECONOMIC ANALYSIS

In general the economic aspects of pre-design studies are well suited to computer application since they are defined logically and can be dealt with quantitatively in every detail. Computer use in this field is well established with numerous programs in existence to calculate the economic feasibility of new projects. To the user, the programs differ mainly in the degree of sophistication underlying the analysis and in the input and output formats used. Traditionally, the information needed to carry out this kind of analysis has been encoded on punched cards. The output is produced in the form of lengthy financial reports. One alternative, requiring time-sharing typewriter terminals, allows the user to converse with the computer and ask for specific information relating to the economic feasibility of the project. Another alternative supplements or substitutes written information and lists of numbers with diagrams that provide comparative financial information at a glance. Rates of return under different conditions may be presented in this form as may cash flow projections and other factors that require consideration in the pre-design stages of a project. In a few installations this kind of information is at the fingertips of senior executives who have had cathode ray tubes (CRTs), which look like television screens with keyboard controls, installed in their offices.

The choice of input and output formats, therefore, is to some extent dependent on the availability of specific pieces of peripheral computer equipment. However, even the most basic equipment permits the mapping of economically relevant information in a form that allows it to be directly related to ecological information. Simulations of the kind discussed previously thus can be extended into the realm of economic studies and used to evaluate the desirability of specific new projects from the public sector point of view. Computer use can raise the level of sophistication of cost-benefit studies by relating overall cost and benefits to localized environmental and economic impact considerations.

SOCIAL IMPACT

While the study of ecological and economic impact of building projects is becoming an accepted aspect of planning, their social impact is too often considered intuitively only or not at all. The use of computers opens up opportunities to expand environmental concerns so that they include social considerations. Applications are obvious in such fields as statistical analysis, and the representation of their geographic aspects in the form of maps. However, the concept of mapping can itself be extended to apply to the graphic representation of the quantitative aspects of life styles such as the timing and location of various activities, their overlap and interaction, etc. By programming computers to process masses of detailed survey data and present the result in a form suitable for use in the pre-design phase of projects, both the effects of contemplated projects on existing life styles and the need for specific facilities designed to encourage the evolution of alternative life styles can be evaluated with increased accuracy.

COMPUTERS IN DESIGN

In the early days of computer use, much effort went into the development of programs that would have allowed computers to make independent design decisions. While work in this area proceeds in a few academic institutions, often in connection with research in the field of artificial intelligence, the focus of practice-oriented development work has long shifted to producing computerized design aids rather than robot designers. The trend, therefore, is for computers to support human design activity by dealing with computational aspects of design, supplying the designer with needed information on

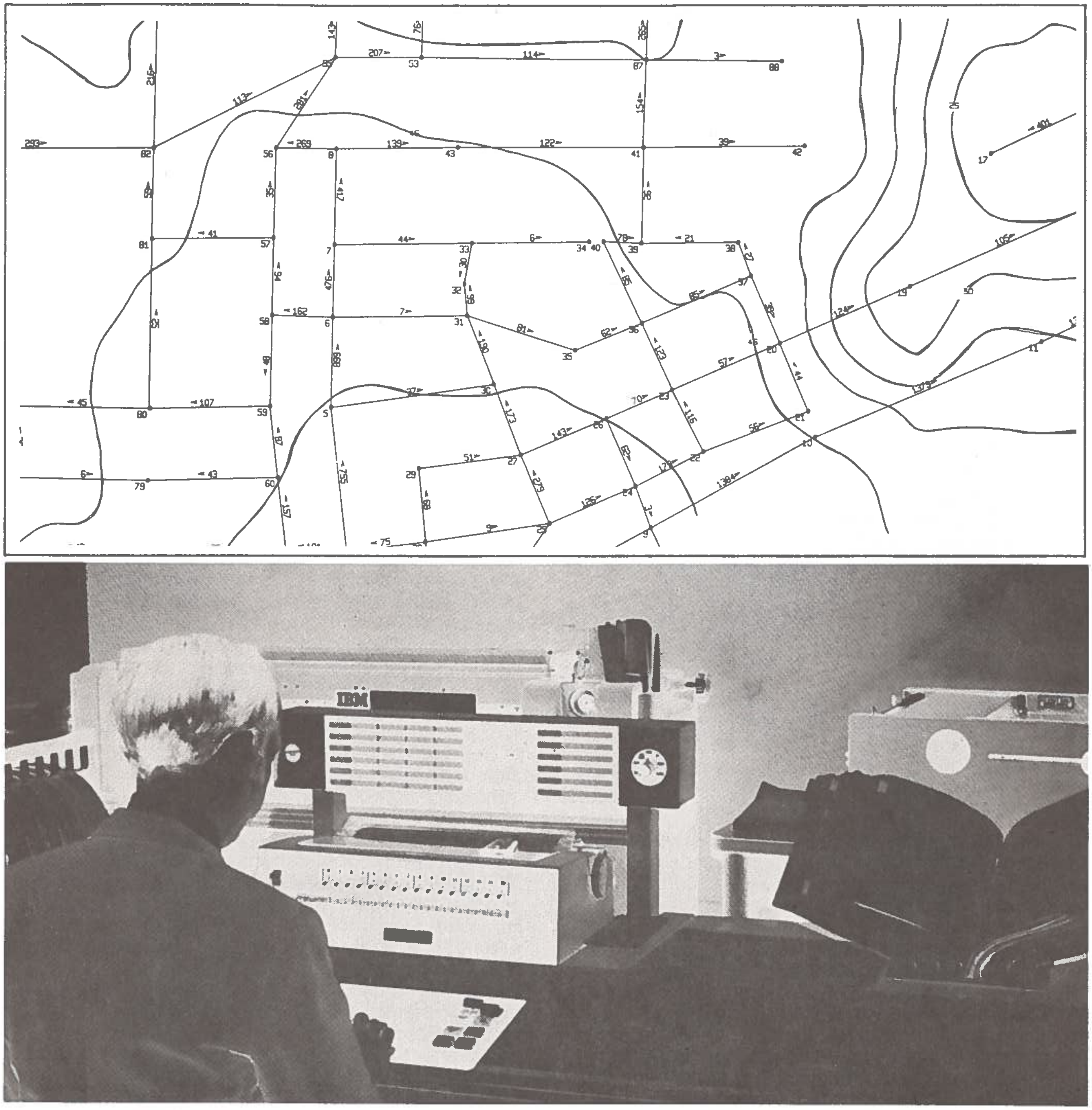


Fig. 2

Contour maps can be useful in displaying other than conventional topographical information. In the case illustrated, a large consulting engineering firm uses an in-house computer system to produce drawings of watermains and residual pressure contours to predict the effect of any proposed change to a water supply system and to analyze alternatives quickly, accurately, and at little cost.

Source: Proctor & Redfern Ltd.

command, and, increasingly, by providing the services of a diligent but somewhat feebleminded draftsman.

More specifically, the computer is proving its usefulness in the following areas:

- Site analysis and landscape design;
- Space allocation and the layout of standard design elements;
- Engineering design and building science;
- Material selection and cost estimating; and
- Specification writing and the preparation of standard drawings.

The few successful attempts by corporations, various agencies and individual design firms to integrate several such applications in comprehensive computerized design support systems suggest, however, that the comprehensive use of computers in project design is still in its infancy. Particularly in situations where building components are standardized and where the design and production processes are under unified control, much greater use of computers can be expected in the future.

SITE ANALYSIS AND LANDSCAPE DESIGN
Problems of building design, unlike those of product design generally, cannot be solved in isolation. Either a building is designed to fit a site, or the site must be adapted to the building's design. In either case, problems of site analysis and landscape design will be encountered. Where large sites are involved, computer mapping programs of the kind discussed previously may be applied. But even where a project is small computers are useful.

An obvious application area for computers is the plotting of aerial perspective and contour maps (Fig. 2). In this case, the computer may translate the elevations and co-ordinates of significant points

Fig. 3

The use of a computer has permitted a developer to keep track of the species, condition and exact location of thousands of individual trees on the site of a planned new town. As a consequence, the location of new buildings and other facilities, such as a new sewer as shown on the illustration, can be analyzed in terms of its effects on existing trees, by having a computer-driven plotter indicate every single tree location in the area affected by sewer construction.

Source: The Cadillac Fairview Corporation Ltd.

on the site (derived from aerial photographs or field surveys) into grid data, or calculate contours or sections through the site at required intervals, and produce finished drawings at specified scales. Some programs also perform a complete cut and fill analysis by comparing alternative grading patterns, and can show the amount of cut and fill required on different parts of the site.

The future will probably see an increased use of computers as an aid in determining planting and development patterns for given sites. Computerized inventories of available stock will be catalogued in terms of cost and suitability for different site and soil conditions, permitting the landscape designer to locate plants on the site plan, keep track of costs, and produce instant layout drawings without leaving the computer console. The process will be aided by the availability of land survey data in easily retrievable digital form. This will permit survey drawings to be plotted automatically at any scale and in any desired format, based on surveying calculations carried out on the computer (Fig. 3).

Computers, however, will also become increasingly useful in technically less sophisticated application. For example, there is a real need for data retrieval systems that would permit site planners to obtain printouts of all the information relevant to the potential use of a piece of land. Such information might concern setback and zoning regulations, site-related building code requirements, height limitations, and the availability of various services. Ideally, systems of this kind would allow planners to call on federal, provincial, regional and municipal data banks, all of them integrated in a comprehensive "Site Planning Information System", and to use computers to assemble and present the information in the form of reports that might include customized maps and diagrams relating to the site in question.

SPACE ALLOCATION AND THE LAYOUT OF STANDARD DESIGN ELEMENTS

Where design decisions are arrived at purely logically, the decision-making process can be simulated on a computer and "designs" generated automatically. However, there are few instances where such conditions apply in the field of building design. One example is the layout of a warehouse. The optimum allocation of space within such a structure would obviously reflect the frequency of shipments of various items, with those in greatest demand located nearest the shipping door. CRAFT and ALDEP were early examples of computer programs written to solve straightforward problems of this type, and to produce simple layout diagrams. Their subsequent application to problems of school, hospital and office building layout was predictably less successful, reflecting the fact that most space allocation problems are much too complex to allow their solution to be simulated mathematically.

Nevertheless, some aspects of space allocation problems do lend themselves to computer analysis. For example, from the study of the social interaction and communication patterns within an organization, we can deduce certain layout requirements. Here, the use of computers in analyzing surveys and organizational data improves the chances of arriving at near optimal space arrangements (Fig. 4). Moreover such information can be linked directly to the requirements for facilities and equipment at individual work stations, and be used to generate computer output that lists, in the case of

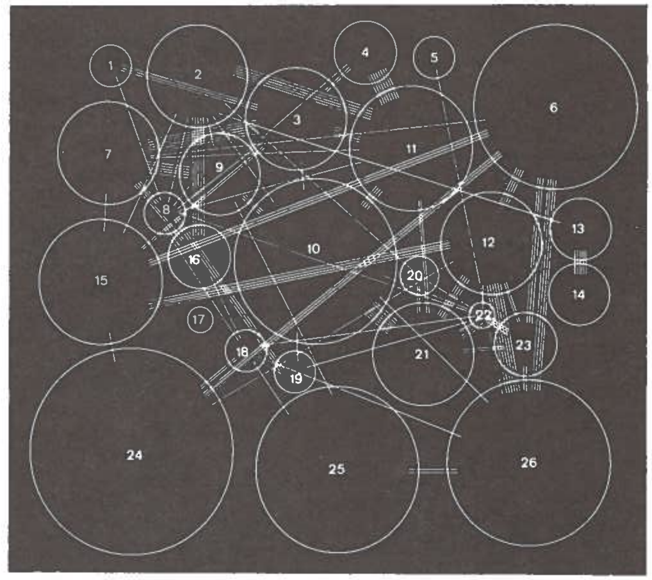


Fig. 4

To achieve near optimal space arrangement in offices, computers can be used to analyze communications patterns within the organization to be accommodated, and to produce charts of the type shown, indicating actual office communication. Frequency of communication is represented by the number of lines between departments as an aid to adjacency layouts, while the diameters of the circles relate to department sizes.

Source: Herman Miller of Canada Ltd.

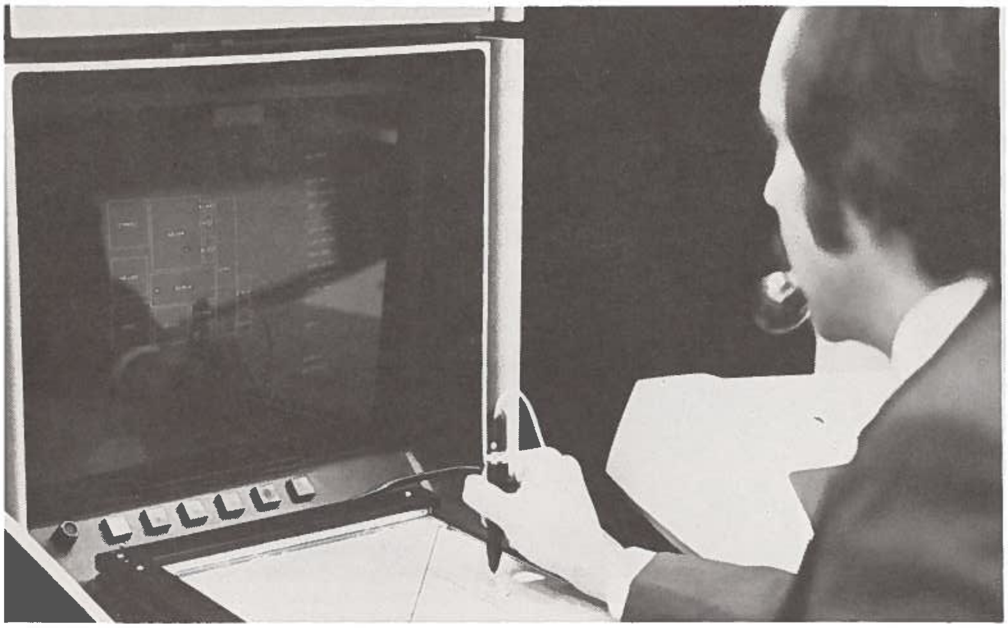
office buildings, all items of furniture and equipment at all work stations. Since such work stations are normally conceived as modular units, they can then be appropriately grouped and arranged within the available space with the aid of computer-generated CRT displays.

The manipulation of two-dimensional modules, e.g. of work stations or furniture on a floor plan, can easily be done with existing computers and program packages (Fig. 5). It is also not difficult to obtain perspective views of the resulting spatial arrangements. The manipulation of pre-designed modules in three-dimensional space, on the other hand, while theoretically no more complex, will probably have to await breakthroughs in the prefabrication of buildings before becoming relevant in practical terms.

ENGINEERING DESIGN AND BUILDING SCIENCE

The field of quantitative analysis represents a well-defined part of the engineers' work. Computer use, therefore, was introduced relatively early and is well established. What problems remain relate mainly to questions of optimal equipment configuration and the comparative advantage of alternative programs. Many of the latter have been developed by user groups, universities, public and industry supported institutes, and individual manufacturers. Most of them are readily available or at least accessible. Such programs may be used to carry out a wide range of engineering calculations, or specifically to design concrete, steel or masonry structures, lighting, piping or duct layouts, etc. In addition to programs that are, for all practical purposes in the public domain, a great variety of program packages are available commercially.

involved a time-consuming search through voluminous printed material. Inevitably, the selection process has tended to favour materials the designer is already familiar with, thus discouraging innovation based on rational analysis. The establishment of the Canadian Construction Information System, for the first time, enables designers to use computers to select building materials quickly and purely rationally from a central data bank. On the basis of a short list of performance and other parameters, the computer searches through the appropriate files, identifies the material or component best suited for the stated purpose, and prints out all necessary information.



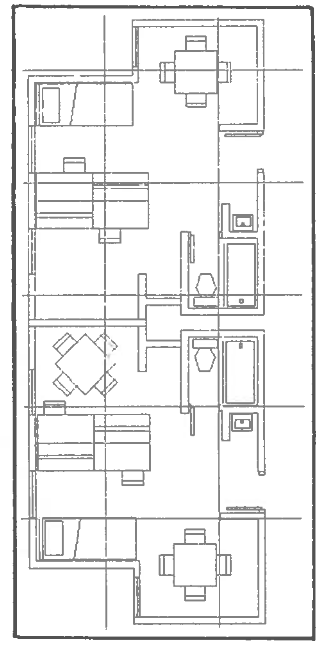


Fig. 5
"ARK-2", one of the few computer program packages developed specifically for use by architects and space planners, permits a designer working at a console to display alternative plan arrangements and to move furniture and equipment at the direction of a light pen. The superimposed reference grid is a feature of the program and can be adjusted or removed at will by the designer operating the display terminal.

Source: Abbey Glen Property Corporation

Apart from pure engineering applications, more recent computer programs have been developed to carry out calculations relating to other scientific aspects of building design. Of particular importance are programs that permit the optimization of building design with regard to energy consumption. There have even been attempts to develop computer programs that would generate optimal building form as a function of environmental input. In view of the need to also consider behavioural, structural, and many other factors in arriving at truly optimal architectural form, efforts aiming at a complete automation of building design should not be taken too seriously in all but exceptional circumstances at least for the present.

More promising is the wider use of mathematical simulation in detail aspects of design that have up to now been dealt with intuitively. Applied so far mainly in the layout of elevator banks and certain transportation facilities, programs such as IBM's General Purpose Simulation System (GPSS) should prove applicable in the solution of many other design problems.

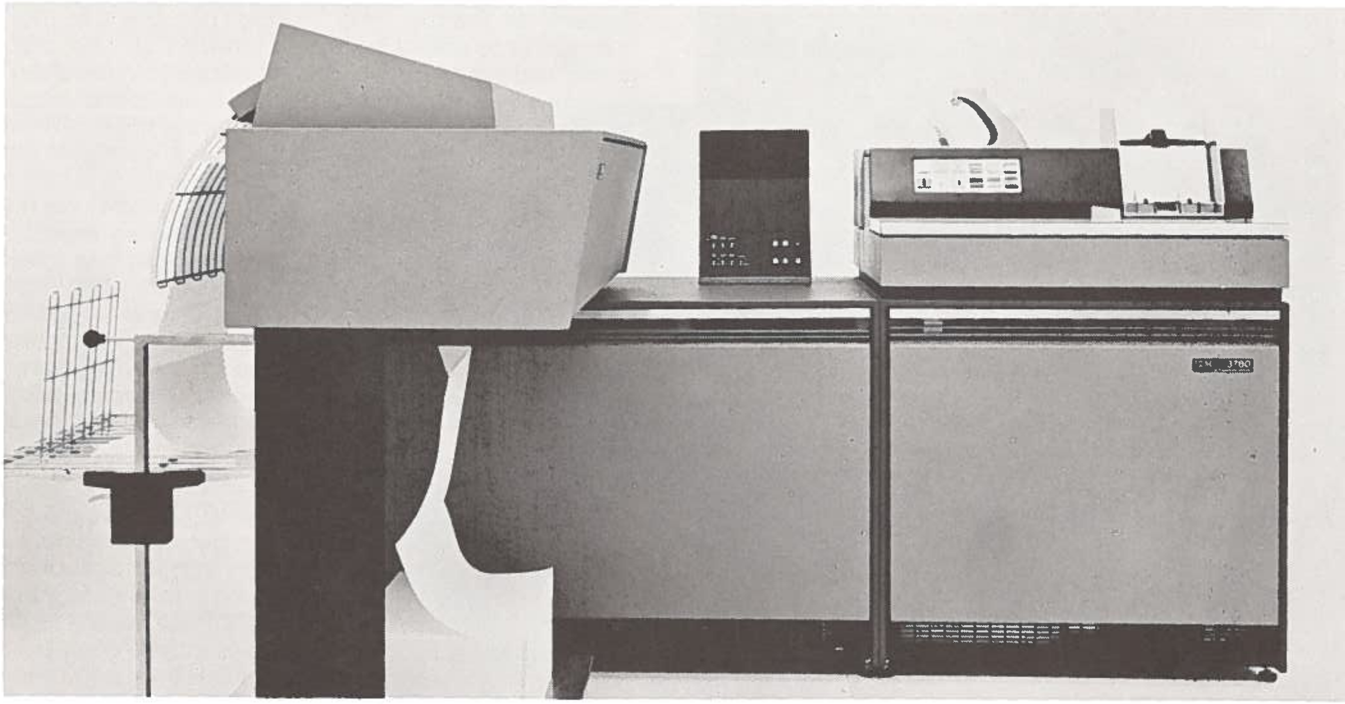
MATERIAL SELECTION AND COST ESTIMATING
Selecting construction materials has traditionally

As additional computer-based data banks are established, this process of rationalization will continue and become increasingly more effective and sophisticated. Information systems relating to specific types of buildings, such as educational or health facilities, will aid in establishing the criteria for selecting specific materials, while material control systems, maintained by implementing agencies, will ensure an adequate supply of materials to the project sites.

Another related area of computer application is that of cost estimating which requires the maintenance of data banks covering material and labour costs, past and present. Since cost estimating is, by definition, concerned more with prices and labour rates at some future date rather than with current costs, computer-aided forecasting techniques, involving the projection of past cost trends or more sophisticated methods, will find increasing application.

SPECIFICATION WRITING AND THE PREPARATION OF STANDARD DRAWINGS

The use of computers in the preparation of specifications would appear to be a logical extension of a computerized material selection process. Instead, computer-aided specification writing preceded the establishment of a central information system by several years. The reason for the early success of computers in this specialty field are obvious: specification writing requires only a relatively small



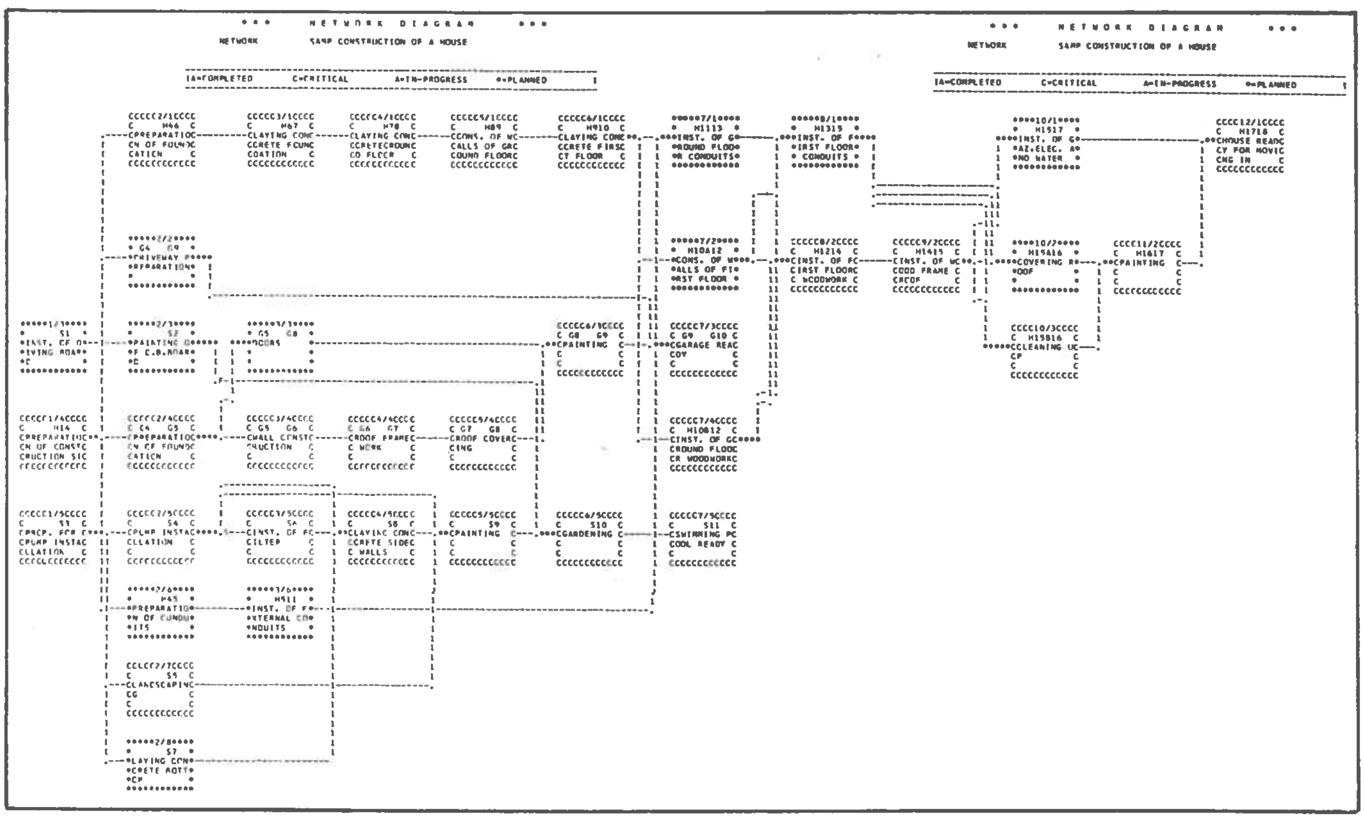


Fig. 6

The ability of computers to generate complete CPM diagrams permits the use of graphic display terminals to analyze the implications of alternative scheduling decisions, before the final network diagram is produced on a line printer terminal such as the IBM 3780 Data Communication Terminal illustrated.

Source: IBM Canada Ltd.

data bank in the form of a master specification, the programming of specification writing routines is simple, and hardware requirements are modest. Since, on the other hand, experienced specification writers are highly qualified specialists, there has been a natural incentive to improve their productivity through the introduction of computers.

Current applications of computers in specification writing generally involve the use of standard programs that allow text and format instructions to be stored in the computer, with the option of editing the basic text in response to individual job requirements. The likely directions of future development in this area are toward a closer integration of computer-aided specification writing with computer-aided material selection on the one hand, and with various aspects of drawing production and contract administration on the other. The output of the material selection process thus would be in a form directly suitable for input into the specification writing process, while the latter would produce instructions to draftsmen and construction administrators in the form of secondary output.

Drafting can be expected to become increasingly computerized in turn, however. With the increasing availability of plotters and rising salaries of draftsmen, standard drawings and then, as rationalization of the building industry increases, all but custom work will be computer-drawn possibly directly on microfilm.

COMPUTERS IN PROJECT ADMINISTRATION

In describing possible trends in computer use in the planning and design of building projects, there have been various suggestions of potential overlap with aspects of project administration. Obvious examples are: the calculation of cash flow projections which can be considered an aspect of resource levelling; the preparation of cost estimates which leads to considerations of cost control; and the print-out of instructions to construction supervisors, generated as a byproduct of computer use in specification writing. It appears that what has happened elsewhere will also happen in the construction industry, in the sense that the introduction of computers will tend to subvert existing organizational structures and impose a new logic on patterns of work flow.

A first manifestation of this trend has been the emergence of "project management" as a new discipline. This draws its strength from the high sophistication of other industries that has been transferred to the administration of construction projects. In general, computers are employed to rationalize production and allow tighter control over all aspects of the construction process. Their application is discussed in the following pages under the headings of scheduling, cost control and resource levelling. It would not be realistic, however, to expect that success in these areas of computer application will not lead to attempts to extend the new methods of scientific management to the hitherto autonomous areas of project planning and design. It will thus be necessary to touch on the possible implication of current trends.

SCHEDULING

In the context of computer application, scheduling relates mostly to the mathematical discipline of network analysis and its practical application in determining the critical path of complex processes. It involves the preparation of network diagrams in which a project is broken down into a series of basic operations and events which are graphically represented by arrows, circles and squares. By listing the time required to carry out each operation, and by identifying the sequential relationships between events, a computer can be used to determine the "critical path", the sequence of operations with the least amount of slack, and therefore allows the completion of the project in the shortest possible time.

CPM programs are applicable only in situations where the time between events can be estimated with a high degree of certainty. Where this is not possible, as for example in the planning phase of a building project, another network analysis technique known as PERT (Program Evaluation and Review Technique) may be used. This is based on the probability of carrying out individual operations within the estimated time spans. If estimating mistakes have been made in either case, the computer offers the advantage of quickly calculating a revised critical path.

The success of critical path analysis programs have been such that it has become unthinkable to carry out really large projects without their use. But in smaller undertakings, as represented by individual building projects, there have been difficulties in the method's implementation. The failures have not been representative for the construction industry as a whole, however. It seems, rather, that available computer programs vary in their usefulness, and that considerable sophistication is required in their application.

Most present computer applications in critical path analysis focus on generating the data that allow hand-drawn critical path diagrams to be prepared afterwards as needed. However, there are computer programs capable of generating CPM diagrams of any complexity, produced as conventional printout (Fig. 6), or for graphic display. The increased use of interactive graphic devices such as CRTs into engineering and management offices will make it possible, therefore, to present the implications of alternative scheduling arrangements instantly in diagrammatic form. The inevitable result will be more effective decision making by management.

COST CONTROL

CPM programs, while an effective management tool, deal only with the timing aspects of complex projects. To manage construction projects effectively, other computer programs are needed to maintain control over costs both internally and in the administration of ongoing projects. In either case, the computer is used for administrative computing and to prepare periodic reports based on input that has been transferred from time sheets, field reports, etc. The quality of these management reports depends obviously not only on the suitability of the computer program producing them, but equally on the quality of the input. It is essential, therefore, that all programming, data collecting, and processing be based on a realistic assessment of the levels of control that can be reasonably maintained over men and materials.

INTEGRATED MANAGEMENT SYSTEMS
The management programs discussed so far are concerned primarily with speeding up construction and related processes and with the convenient retrieval of cost information. The data obtained through these programs, when combined with such techniques as linear programming*, permit the optimal deployment of all resources under management's control. Essentially, these consist of manpower, materials, and financial resources, and must be dealt with in an integral fashion.

Integrated management systems aim to minimize waste of any kind in the operations of an organization. Their introduction is not merely a matter of computer use, however, but may require a total reorientation of management resulting, for example, from a recognition of the need to obtain fuller control over some aspects of ongoing operations. The consequent restructuring of an organization can have far-reaching effects, and touch on almost any aspect of the planning, design, and implementation of the construction projects it undertakes. Nevertheless, in many instances such radical change will have to be accepted if substantial gains in productivity are to be achieved in the construction industry.

Hardware options

A potential user, when considering various alternatives of acquiring or gaining access to computers, has essentially three options:

1. He may acquire a microcomputer to meet personal computing needs or to serve specific functions within his organization;
2. He may rent a time-sharing terminal that gives access to a large central computer operated by a service bureau; or
3. He may lease (or buy) an integrated in-house computer system tailored to the needs of his organization.

Whatever the decision, its implications for the user's subsequent approach to problem solving can be serious and must be considered in detail.

MICROCOMPUTERS
Microcomputers are the most recent addition to the basic range of computer hardware. They are built around microprocessors that occupy no more than a few chips of silicon but, in effect, pack several thousand transistors in a few square millimetres. By adding memory and circuitry to permit communication with the outside world, fully operational computers are created at a cost of no more than a fraction of conventional models. At their

*Linear programming is a mathematical technique that permits — with a minimum of computation — the selection of an optimum strategy in the deployment of resources to achieve a stated objective. The technique is relatively new, but has obvious potential applications in construction and other planning problems.

```
INVESTMENT ANALYSIS IN REAL ESTATE
(100 UNIT APARTMENT - 1975)

                                              R
                                         38   R
                                         CO   J
INPUT

BUILDING COST             1800000             S
LAND COST                  100000             S

                              250             ↓
                               12          X
                          3000.00          A  ◊
                              100          X
GROSS INCOME            300000.00          A  ◊
                                              S
                           300000             ↓
                             0.45          X
OPERATING EXPENSES      135000.00          A  ◊
                                              S

PROBABLE 1ST MORTGAGE         75%             S
MORTGAGE INTEREST           10.5%             S
# OF YEARS OF REPAYMENT      25               S
INTEREST TIME COMPUTATION     2     YEARLYS

PROBABLE 2ND MORTGAGE         20%             S
MORTGAGE INTEREST             12%             S
# OF YEARS OF REPAYMENT      25               S
INTEREST TIME COMPUTATION     2    YEARLYS

BUILDING DEPRECIATION         2               S
TAX BUILDING DEPRECIATION     5               S

                                              S
CAPITALIZATION RATE        11.85%          A  ◊
OWNER TAX                     25%             S
CAPITAL GAIN TAX              50%             S

# OF YEARS CONSIDERED        10               S
```

simplest, microcomputers are programmable calculators or special-purpose control devices built into typewriters or other machinery. Some microcomputers, on the other hand, have expandable memories and can be linked to conventional keyboard terminals, a variety of storage devices, line printers, etc. At that point, they become competitive in every way but size with conventional data processing systems, with comparable operational advantages and disadvantages.

In between these extremes, the market offers a range of microcomputers ideally suited for certain applications in the construction industry. Unlike larger computers, they do not permit the use of conventional computer languages like FORTRAN. Such microcomputers require instructions in specially coded form with which the user must first become familiar. Due to the computers' simplicity, complex calculations must be broken down into simpler elements. The results of such calculations may not be as accurate as those obtainable on large computers, and will not be produced as fast. Output format is far simpler than conventional computer printout and limited to essential information (Fig. 7).

In certain applications however, none of these drawbacks are crucially important. While conventional computer languages may not be admissible, the user is able to instruct the machine without the help of professional programmers. Except in sophisticated engineering and business applications, complex calculations are rarely needed in the construction industry. The high level of accuracy large computers are capable of is also not

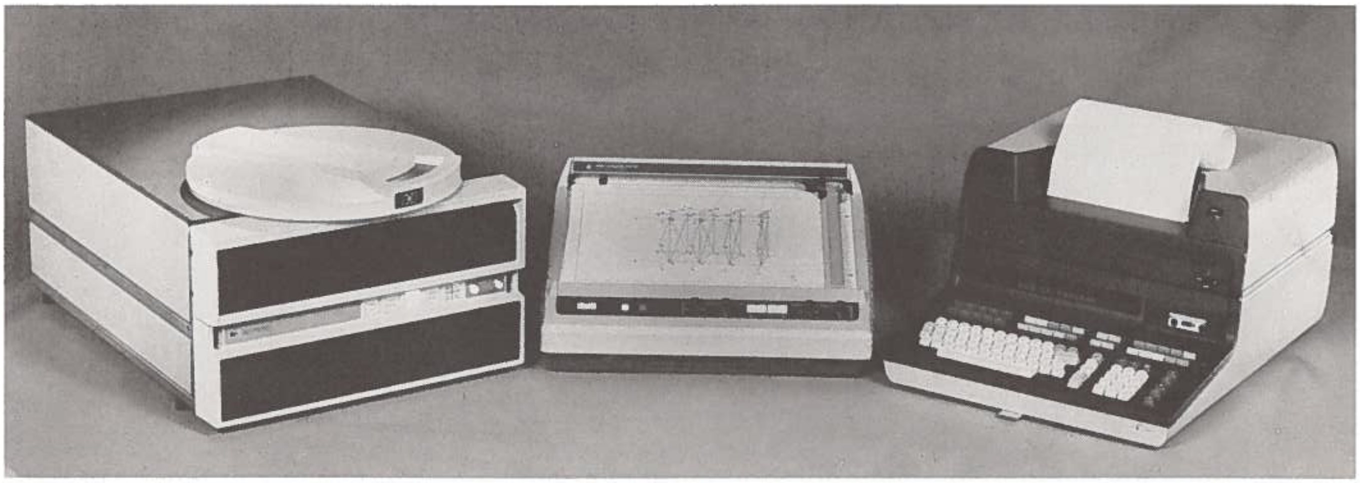
Fig. 7

A microcomputer can be an invaluable aid to a professional in his daily work. The illustration shows an architect's office using two different Olivetti computers for tasks ranging from conventional office calculations, investment analyses, structural calculations, the drawing of perspectives, heat loss calculations, etc. The format of the output is illustrated in an example, with explanatory headings added.

Source: Aldo Riva Architect, Toronto

significant in such areas as cost estimating or simple structural calculations, to mention only two examples. The simple output format may be welcome to users who know exactly what the computer is programmed to do. Also, the disadvantage of slow speed can be compensated for by scheduling drawn-out computations during nights and weekends when there is no other use for the computer.

The most important consideration in evaluating microcomputers is of course their low capital and operating costs. One or more of them, depending on size and model, may be bought outright at the cost of mere access to a large time-sharing computer. Moreover costs are predictable. And since programs and programming are simple, a user can write his own program tailored to his personal requirements, or acquire existing short programs at little cost. Above all, there is no need for specialized staff to deal with data processing problems. Last but not least, some of the microcomputers on the market allow for modular expansion to the point where they can be used in conjunction with large time-sharing facilities or with the normal range of peripheral equipment usually associated with larger computer systems such as storage devices, line printers and cathode ray tubes (Fig. 8).



A.J.VERMEULEN
322 KING STREET WEST
TORONTO 416 862 1720

CIVIC CENTRE
MAY 1975
OAA RAIC
GROSS FLOOR AREA 26231SF

	ELEMENT	RATIO	QUANTITY	RATE	AMOUNT	COST PER SF		TOTAL	%
1	SUBSTRUCTURE				62291				
	(A) NORMAL FDNS.	0.00	0SF	0.00	0	0.00			
	(B) BASEMENT EX&B	3.86	101313CF	0.27	27291	1.04			
	(C) SPECIAL FDNS.				35000	1.33	2.37	62291	5
2	STRUCTURE	1.32	34619SF	3.79	131300				
	(A) LOWEST FLOOR	0.31	8104SF	1.27	10300	0.39			
	(B) UPPER FLOORS	0.69	18127SF	5.02	91000	3.47			
	(C) ROOF CONSTRN.	0.32	8388SF	3.58	30000	1.14	5.01	131300	11
3	EXTERIOR CLADDING	1.02	26738SF	5.48	146400				
	(A) ROOF FINISH	0.32	8388SF	2.15	18000	0.69			
	(B) WALLS BELLOW	0.17	4500SF	6.00	27000	1.03			
	(C) WALLS ABOVE	0.36	9550SF	6.28	60000	2.29			
	(D) WINDOWS	0.14	3690SF	10.00	36900	1.41			
	(E) DOORS & SCRNS	0.01	225SF	13.33	3000	0.11			
	(F) PROJECTIONS	0.01	385SF	3.90	1500	0.06	5.58	146400	12

Fig. 8

Some modern desk-top computers come with optional disk-drives and plotters. They can be programmed in a high-level language and used in a wide range of professional and business applications. A sample of output from such a computer shows a summary of construction costs, based on the CIQS elemental method of measurement analysis, prepared by a quantity surveyor using his own HP 9830 computer.

Sources: Hewlett-Packard Canada Ltd.
A. J. Vermeulen, Quantity Surveyor, Toronto

TIME-SHARING TERMINALS

In contrast to microcomputers which joined the lineup of available hardware options quite recently, the use of time-sharing terminals connected to large computers is well established. They allow users access to the computing power of a large system without any capital investment and with a minimum commitment of staff resources and time. By following certain rules, input can be introduced over a typewriter or teletype terminal and output

```
(A)→      )LOAD 56010 RKVMAPS
   SAVED   15.54.58 10/09/74

    →      )COPY 56010 RKVMAPFUN DEFCWM ASSIGN1 CHPRINT
   SAVED   15.56.05 10/09/74

(B)→      DEFCWM 50 70
   CHARACTER WORKING-MAP 50 BY 70 DEFINED

          '~' ASSIGN1 RIVER∨LAKE
(C)       '∘' ASSIGN1 SWAMP
          'Δ' ASSIGN1 FOREST
          '.' ASSIGN1 SLOPE

(D)→      CHPRINT
   ENTER TITLE
    →AREAS ON MAP SUITABLE FOR RESIDENTIAL DEVELOPMENT
   ENTER NUMBER OF DESIRED OUTPUT OPTION
   POSITION NEW PAGE AND PRES RETURN,OPTIONS ARE:
       1. BARE MAP
       2. FRAMED MAP
       3. COORD. FRAMED MAP
       4. COORD. BARE MAP
   ⎕:

(E)→      3
                AREAS ON MAP SUITABLE FOR RESIDENTIAL DEVELOPMENT
```

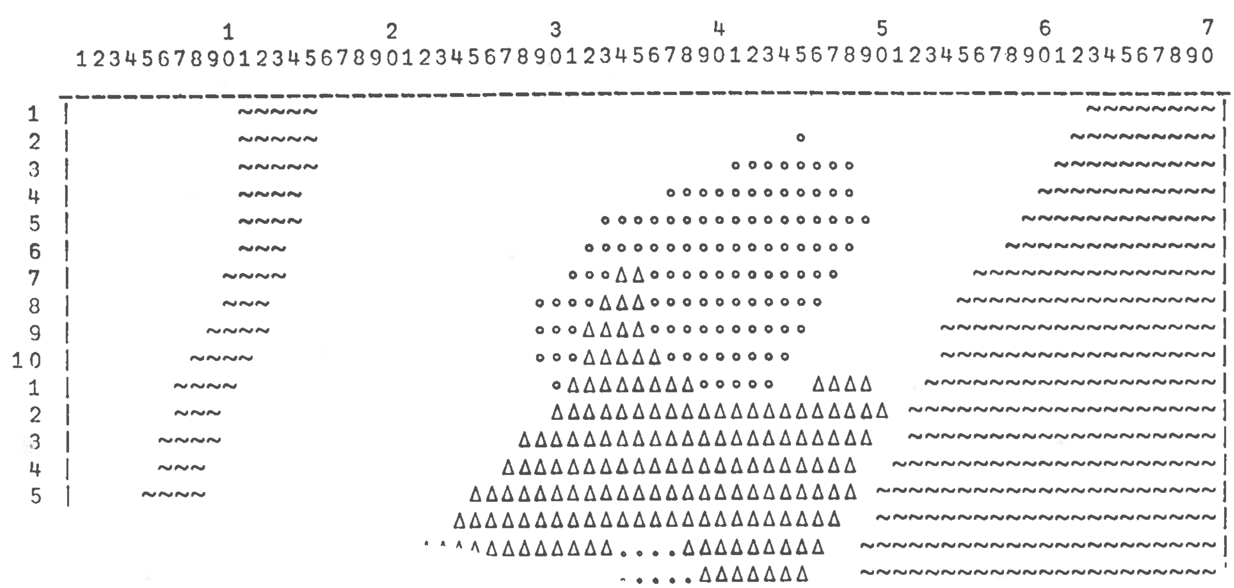


Fig. 9

Time-sharing can include the production of computer-generated graphic output. In the example illustrated, an APL program allows maps to be produced on a terminal, based on data and programs stored in the computer. All that is involved is the retrieval of data and the necessary program elements from known files (A), followed by the definition of the desired map size (B), the assignment of keyboard characters to terrain aspects that, in this case, render land unsuitable for residential development (C), a title (D), and a choice among four types of map formats (E). The output can be presented on any graphic display device or, as shown here, on a typewriter terminal. Typewriter terminals are also available as portables that can be used wherever there is a telephone.

Source: University of Toronto, Department of Architecture can be obtained on the same terminal upon entering certain command words. No knowledge of computer languages is required as long as existing package programs are used exclusively.

A previously mentioned example of time-sharing is the use of the computer-based construction information system established and maintained by the Canadian Construction Information Corporation with headquarters in Ottawa. In this case, subscribers to the Corporation's services anywhere in Canada can obtain building product information by typing in their requirements in terms of given parameters. Another example is the use of time-sharing terminals to produce computer-generated construction specifications. A third example is the periodic entry of bookkeeping items that permits a remote computer to keep accounts and to produce up-to-date financial reports on command. While the same keyboard terminal may be used every time, a different computer will likely be addressed in each of the cases mentioned simply by varying the sign-on procedure.

An important variation of conventional time-sharing is the use of conversational languages. Instead of entering all the needed data and then calling for the required printout, the user enters data in response to questions posed by the computer. The resulting man-machine interaction permits the consideration and evaluation of alternative solutions to a problem in the context of a potentially synergetic process. Particularly in many aspects of planning and design, the conversational use of computers can be expected to grow in importance, especially if existing government-maintained data banks should become directly accessible (Fig. 9).

Rather than enter data only, to have them dealt with in accordance with a program provided by the computer centre, a terminal user has the option of using his own programs. These may be stored on electromagnetic tapes or disks at the central computer installation. If the programs are short they may be entered manually via a typewriter keyboard when they are to be used, or they may be stored on punched cards or tape and entered through a card reader or other device installed in the subscriber's office. The availability of card readers opens the option of entering large quantities of data for processing in a central computer. However, at this point the simple keyboard terminal will have become inadequate to handle the increased stream of output, and must be supplemented by printers that can produce output at a rate of several hundred or more lines per minute.

The costs of maintaining an elaborate time-sharing installation obviously are high. They are justified where computing or data-processing problems are complex enough to require the use of a large computer but do not occur often enough or with sufficient regularity to justify the installation of a separate computer of sufficient size.

IN-HOUSE COMPUTER SYSTEMS

If the use of microcomputers or time-sharing increases within an organization, the point may eventually be reached where the installation of an in-house computer system must be considered. The reasons are different in each case. Microcomputer users will find that the limited capacity or the specialized nature of their equipment renders it unsatisfactory for general data processing tasks. On the other hand, subscribers to time-sharing services will find that their costs keep rising proportionately to the expansion of computer use even after they have reached levels that exceed the combined capital and operating costs of an in-house computer system.

The decision to install an in-house system involves a major financial commitment in terms of capital expenditures or leasing arrangements, and normally the establishment of a department or separate organization dedicated to its operation. The technical and economic success of the operation, beginning with the choice of equipment and software, depends primarily on the qualifications and experience of the staff charged with the planning and implementation of the system.

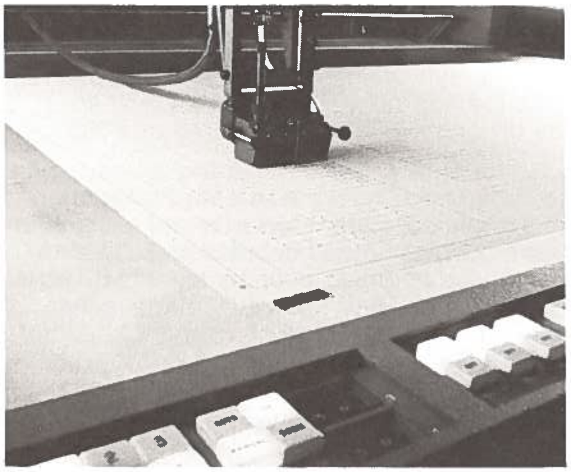
The options vary greatly. By adding memory, data storage devices and peripheral equipment, some microcomputers can be converted into minicomputer systems that "read" drawings (through digitizers), produce typescripts, standard format printouts, plans and diagrams, and can be used as terminals for running large programs on a remote time-sharing system. Time-sharing, in this case, becomes a feature added to reduce occasional peak loads that would otherwise have to be handled on a correspondingly larger in-house computer system. However, the same amount of money may buy substantially more computing power if the range of in-house peripheral equipment is reduced, for example, to a single line printer and card puncher needed to prepare input. Graphic output might be limited, as a result, to the kind of imagery that can be produced on a line printer through the overprinting of characters. Alternatively, graphic output may be produced as the need arises on plotters operated by a specialized service organization from magnetic tape output generated on the in-house computer.

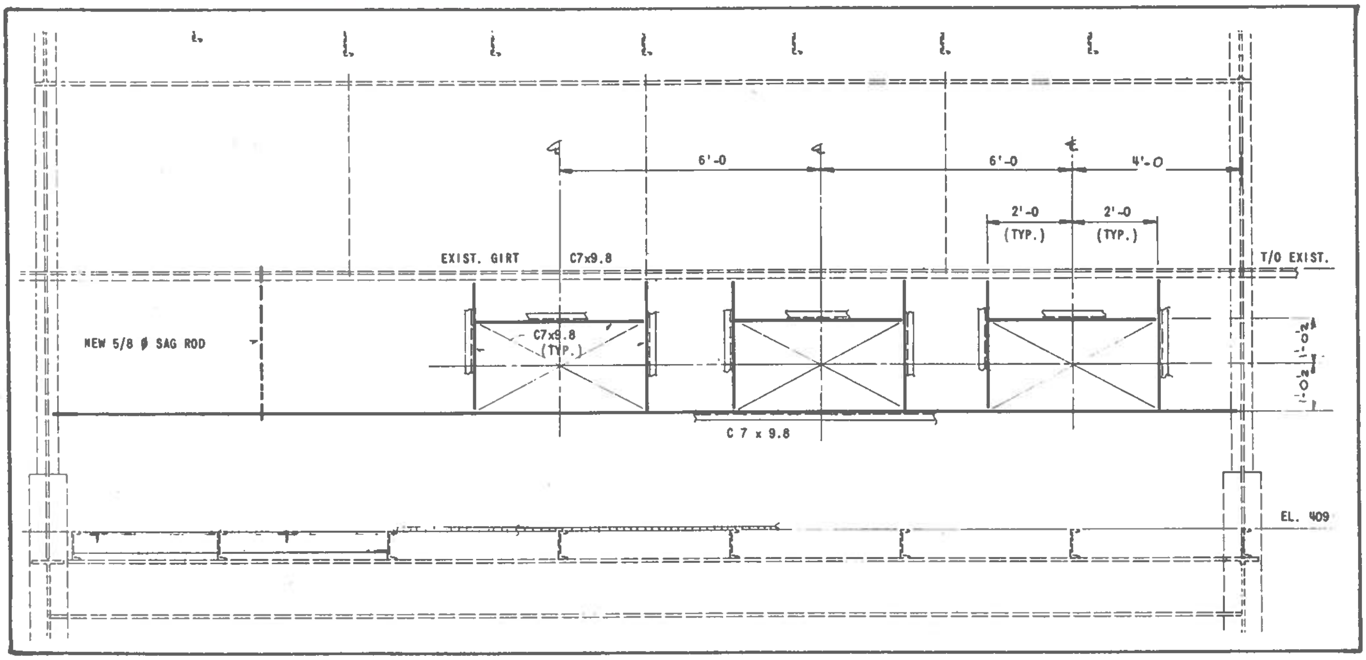
The power of a computer determines not so much the things it can do but rather the speed at which a given data processing job can be carried out and

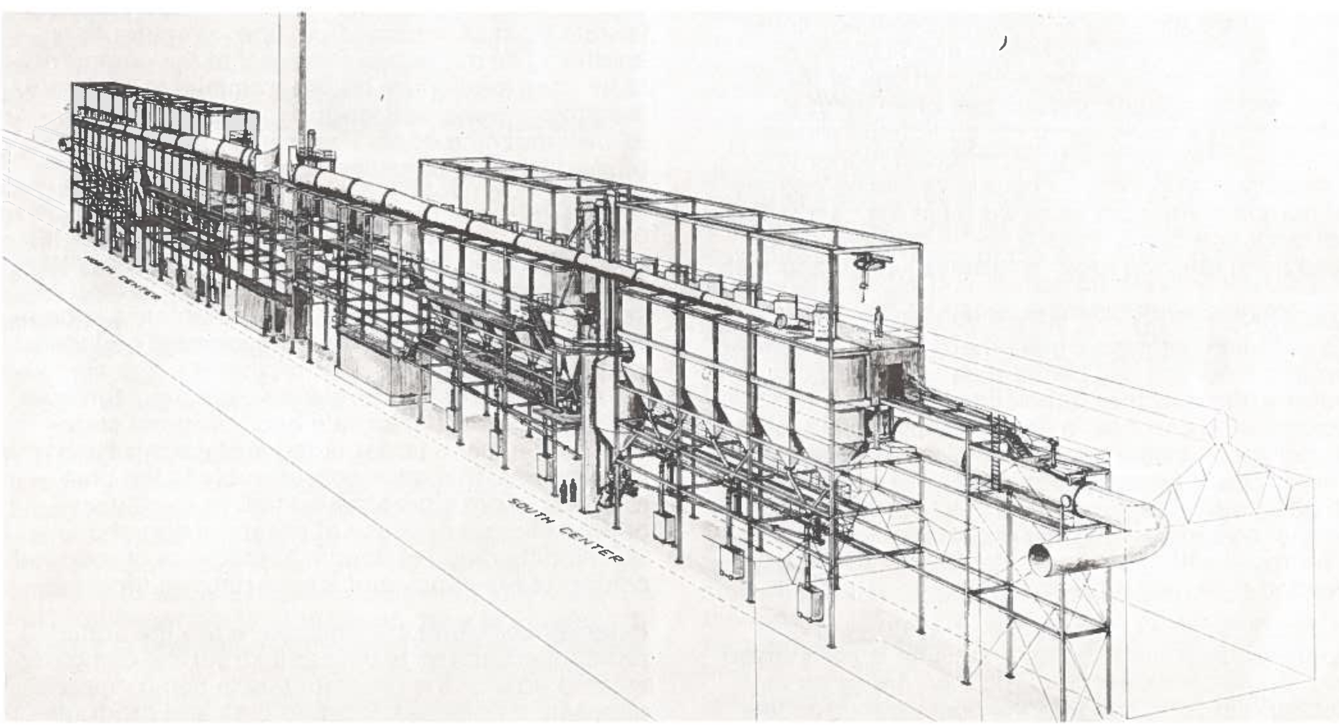
Fig. 10

Possibly one of the most advanced computerized drafting systems in the world is in operation at Alcan headquarters in Montreal. It consists of two flatbed plotters, a CRT terminal, a digitizer and a card reader, linked to two minicomputers which can in turn be connected to a large central computer. Information is digitized on the basis of design sketches that have been prepared by an engineer, with working drawings prepared on one of the plotters and completed by hand. Plotters are also used to prepare large (five feet long) perspectives of the kind shown.

Source: Aluminum Company of Canada Ltd., Montreal




6'-0
6'-0
4'-0
2'-0
(TYP.)
2'-0
(TYP.)
EXIST. GIRT
C7x9.8
T/O EXIST.
NEW 5/8 ⌀ SAG ROD
C7x9.8
(TYP.)
C 7 x 9.8
EL. 409


NORTH CENTER
SOUTH CENTER

the number of tasks that can be accomplished simultaneously. In principle, computing problems of any complexity can be solved on any computer. To undertake complex jobs on a small computer, however, means that they have to be broken down into sequences of simple routines. It may, therefore, take too much time to carry out major tasks on a small computer. This problem becomes acute where a process such as architectural design requires more or less instant visual feedback from the computer. When used in this context, even minicomputer systems of substantial size require full dedication to the operation of a single graphic terminal while simple graphic elements are moved around on a CRT screen, or while a perspective view of a building is being generated. Computer-equipped work stations in a design office thus will almost inevitably have to be linked to a large time-sharing system and, even then, will tend to focus on specialized design tasks or building types.

In view of the financial and manpower resources needed to develop elaborate program packages to the point where they are fully operational, it is not surprising that leadership in this field has passed from individuals and small consulting firms to governments and large corporations, particularly in the metal fabricating sector of the building industry (Fig. 10).

Programs and programming

PROGRAMMING LANGUAGES AND THEIR CHARACTERISTICS

What distinguishes minicomputer and larger systems more than anything else from a microcomputer is their ability to respond to higher level programming languages. While the programming of a microcomputer involves a machine-oriented language or coding process that is more or less unique to the particular type or model of computer, the programming of larger computers can be done in one of a number of universal problem-oriented languages like COBOL, BASIC and FORTRAN. Large program packages written in one of these standard languages, in turn, can often be used without any knowledge of the computer language employed, thanks to a superimposed higher level language that is in many cases composed entirely of numbers and command words in the user's natural language. Such "high level" languages have also been referred to as "user-oriented" languages.

MACHINE-ORIENTED LANGUAGES

As the name suggests, machine-oriented languages are the kind that can be "understood" by a computer without further translation. To instruct a small computer to carry out a set of complex calculations or logical operations, it may therefore be necessary to describe every single step the computer has to go through to arrive at the desired result. This can involve identifying the exact location or "address" within the computer memory where needed data may be found.

Normally such a program is first written out on appropriate coding sheets. Each line is transferred to a single computer card and then the complete deck of cards is read into the computer through a piece of equipment called a card reader. Alternatively, in particular on microcomputers, information from coding sheets is entered into the computer directly via the appropriate keyboard. Once entered, the program will likely be stored on electromagnetic tape or disc.

On large computers, machine-oriented languages are more complex and are referred to as "assembler languages" in which sets of detailed step-by-step instructions have been replaced by so-called macro-instructions. Their main advantage is that they make minimum demands on memory capacity and therefore permit a computer to perform with greater efficiency than if higher level languages were used. Assembler programming may thus utilize a minicomputer for tasks that would otherwise require a much larger machine. However, savings resulting from improved machine efficiency may be more than offset by the higher cost of assembler programming when compared with the cost of programming in a higher level language.

PROBLEM-ORIENTED LANGUAGES

By using problem-oriented languages, two major disadvantages of assembler languages can be overcome. Since problem-oriented languages address the computer at a "higher level", much of the tedium involved in spelling out detailed machine instruction is alleviated. This occurs because statements in a problem-oriented language relate to the sequence of steps necessary to solve the problem. In contrast, every statement written in an assembler language translates into a single machine instruction or, at best, in the case of macro-instructions, into a specific set of machine instructions. Moreover, every computer understands only its own machine language so a program prepared in an assembler language has to be rewritten in its entirety if another computer is to be used to solve the same problem. Programs written in such languages as FORTRAN, BASIC and COBOL, on the other hand, are readily transferable most of the time from one computer to another. The major provision is that the computer to be used can in turn be programmed to translate the problem-oriented language in question into its own machine code. This translation is accomplished through so-called compilers.

Since compilers for the more popular problem-oriented languages are commercially available for all medium and large computers, programs written in those languages are nearly universal in their applicability. Before they can be read into the computer, however, its core or memory must be loaded with the appropriate compiler, thereby reducing the machine's net performance capacity. Moreover, the compiler must translate each program statement into a much larger number of machine instructions. This adds considerably to the time required to run a program written in a problem-oriented language. Ease of programming and universality thus are bought at the price of reduced computer efficiency and longer running times.

In larger computer systems, there are the added difficulties such as having to instruct the computer what to do with the program that is being entered, choosing a compiler, locating data and program packages referred to in the program that may be stored somewhere in the system, and determining what special output requirements may have to be met (such as special paper for the printout). The operating systems that deal with such items, as well as establishing the order in which incoming programs are executed, are so complex that they require the use of additional special languages, called JCL (Job Control Language) in the case of large IBM installations.

Normally, the user will not come into direct contact with the problems associated with operating a large computer system. There are indeed languages that permit him to remain oblivious to such problems and still converse directly with the most powerful computers. Probably the best example of a language designed for this purpose is APL (A Programming Language) which allows a typewriter terminal to be used both as a simple and extremely powerful desk calculator and as a text-editing facility, and also to enter and control sophisticated programs of any complexity.

USER-ORIENTED LANGUAGES

With user-oriented languages, the actual programs and data can be stored in the computer with their location noted in a program "library". The program may be written in APL which uses abstract symbols only, but a user-oriented language permits a person to operate the program without having any knowledge of programming. Similar conditions apply in the use of many other program packages. They may be written in FORTRAN or COBOL or some other language but all their users need to know are the appropriate code words and input format for commands and data.

The trend of making computer use independent of any knowledge of assembler or the traditional problem-oriented languages has resulted in the emergence of powerful user-oriented languages that allow users, even those unfamiliar with computers or data processing, to have access to large systems after only a few hours of instruction. An example of such a language is the MARK IV system that has started to replace COBOL in many business applications.

User-oriented languages are particularly important in the field of computer graphics where they allow a person working at an interactive display console to generate images, move them about, change their scale, etc., without any knowledge of computer programming. An example of such a graphic language is GRAPPLE, intended for use in the Federal Department of Public Works' CAD (Computer Aided Design) project.

WRITING OF PROGRAMS

In most business applications, computers are introduced because proven programs are commercially available to do time-consuming or tedious jobs. Once computer use is established there is a natural tendency to apply available equipment and accumulating expertise to other tasks. New programs will tend to be written in the languages with which the staff is familiar and which can be run on the available computer. Less frequently, a task for which no known program exists is identified initially as suited for computerization. One or more systems analysts and/or programmers will then be put to the task of writing the necessary programs to be run on what appears to be the most suitable computer system. Often the programmers will be on the staff of an established data processing firm that sells computer services and will likely be partial to their own in-house equipment.

Regardless of the circumstances, the writing of programs must be considered in the context of the particular computer system on which they are to be run. The production capacity of a small in-house computer, for example, can obviously be improved if programs are written in its assembler language. However, this will place added demands on programmers, always assuming that professionals sufficiently familiar with the particular computer can be attracted, or trained for the task. The cost of preparing such programs will have to be fully amortized over the time during which the particular computer is in use since they will not be transferable to another system. The trade-offs between programming costs and computer operating costs thus will have to be examined in detail, including the largely unpredictable benefits to an organization that may accrue from being forced to rethink its data processing approach every few years in the light of newer technological advances.

The latter is of importance because computer programs doing the same tasks may differ not only in terms of the language employed but, more importantly, in terms of their underlying algorithm. The algorithm defines the series of logical steps by which a problem can be solved, with alternative algorithms often available for one and the same mathematical problem. When a problem is too difficult to solve in a logical step-by-step manner, it may be approached, alternatively, through the use of heuristic methods — computer techniques that are based on trial and error. Different programs, moreover, may approach problem solving in different ways; some aiming to maximize the use of computers, others focusing on the solution of those parts of problems that are well suited to computer assistance and aiming at an optimum man-machine interface. A complex computer program to draw perspective views of buildings may thus be prepared at great expense whereas, at little cost, a microcomputer could be easily programmed to calculate the position of the significant points of the perspective with a draftsman drawing the connecting lines. In all cases, a program's structure may be presented in the form of a flow chart in which the logic of the solution is displayed graphically (Fig. 11).

THE USE AND ACQUISITION OF PROGRAMS

Because of the difficulties and costs of developing proprietary computer programs, the temptation to acquire or use someone else's existing programs is often irresistible. To do so also makes sense sometimes. For example, the computerization of marginal activities, such as accounting in a small firm, rarely justifies the hiring of systems analysts and programmers. Commercial data processing services that can satisfy the particular requirements are likely to be found easily. The users of such services, in fact, apply existing programs without needing to know anything about them.

The availability of specific program packages designed to run on specific computers, on the other hand, can be a major consideration in the acquisition of computer hardware. This applies equally in the cases of programmable pocket calculators, microcomputers, minicomputer systems, and large computers. The most successful and complex of such programs have been perfected over many years and would be hard to duplicate. Examples are the ICES (Integrated Civil Engineering System) programs developed at the Massachusetts Institute of Technology, APEC (Automated Procedures for Engineering Consultants) programs developed by an independent user group in the United States, and the SYMAP family of computer-mapping programs (SYMAP, GRID, SYMVU, etc.) developed at Harvard University. In all these cases, programs are available at a nominal cost from nonprofit organizations which also provide the necessary documentation and program support. Similar support is also available from computer manufacturers for programs developed for their customers' use.

Without such support, the use of a program may prove much more costly than anticipated at the time of acquisition. Even after the "bugs", with which new programs are normally blessed, have been ironed out the transfer of the program from one computer to another may cause unforeseen difficulties. Identical computers may use different operating systems that will require adjustments in the program. If it is written in one of the standard problem-oriented languages, differences in the compilers may cause translation difficulties, or the documentation accompanying the program may prove inadequate with the result that the new user cannot operate it.

Another kind of problem associated with the use of acquired computer programs is that of responsibility. Particularly in professional work, the involvement of computers in such activities as engineering calculations, material selection and specification writing does not absolve the user from normal responsibility. Miscalculations and wrong decisions cannot be blamed on a faulty computer program or an incompetent computer operator. Professionals depending on computers owe it to themselves to be fully familiar with the programs they are using. On the other hand, the public will have to be protected from misuses of computers by nonprofessionals who, more and more, will be in a position to carry out complex computations and arrive at involved professional decisions without necessarily being aware of the implications of their actions.

As things stand, there are no statutory limitations on the use of computer programs and there is little protection through copyright. This situation has contributed to the strong expansion of the use of computers since the time of their initial introduction. It also imposes constraints on access to proprietary programs, since the lack of copyright protection makes anything but an outright sale of a program in its original form commercially risky. Where there is an incentive to sell a program, it is therefore often offered in binary form. This allows it to be run on specific computers but makes it impossible to comprehend the conceptual basis of the program. Due to understandable security precautions, such programs have to be run "blind", making their application to all but the most trivial professional tasks unacceptable.

An alternative is to look for programs that are in the public domain and to adapt them to the user's specific requirements. The most obvious sources for such programs are university libraries and governments. Programs found there are not normally supported, but the documentation provided should be sufficient to serve an introductory purpose. Before embarking on far-flung searches for particular programs, however, their probable cost should in all cases be compared with that of having the required programming work done in-house or under contract.

COMPATIBILITY OF PROGRAMS

The sheer number of computer programs that have been written and may be available in one form or another makes it imperative that great care is exercised when new program libraries are established. It is important to remember in this context that the programs used by a firm must not only respond to ongoing needs but allow optimum use to be made of computers while making minimum demands on staff time. In the area of computer use, a focus on program aspects (software) may therefore provide a sounder basis for corporate planning than the traditional focus on equipment (hardware).

In the early stages of computer use planning, decisions are thus required that identify the kinds of programs to be written or acquired. The programs in turn will suggest a range of computers on which they can be run and indicate probable time-sharing or equipment costs. However, before the choice of programs, services and equipment is narrowed down, another major element must be introduced into the calculations — that of the cost of operating the equipment and maintaining the software.

Dealing with software obviously requires a knowledge of programming. While most professional programmers are familiar with several computer languages, it is nevertheless not always possible to find staff with the ideal combination of knowledge and experience. In an actual situation, a user may decide early that his staff will have to be familiar with FORTRAN and COBOL because of the ready availability of certain program packages. Furthermore, he may want the computer to be used interactively as much as possible and require, therefore, that in-house programming be done predominantly in APL. Should his plans by chance include leasing or buying an in-house computer, which for reasons of operating efficiency should be programmed in an assembler language at least for all repetitive tasks, a minimum staff of three experienced professionals would in the end be required to operate what might be a relatively simple system.

In the above example, an alternative plan might sacrifice in-house computing capability, leave the maintenance of existing program packages to a service organization operating a time-sharing system, and concentrate on developing new APL

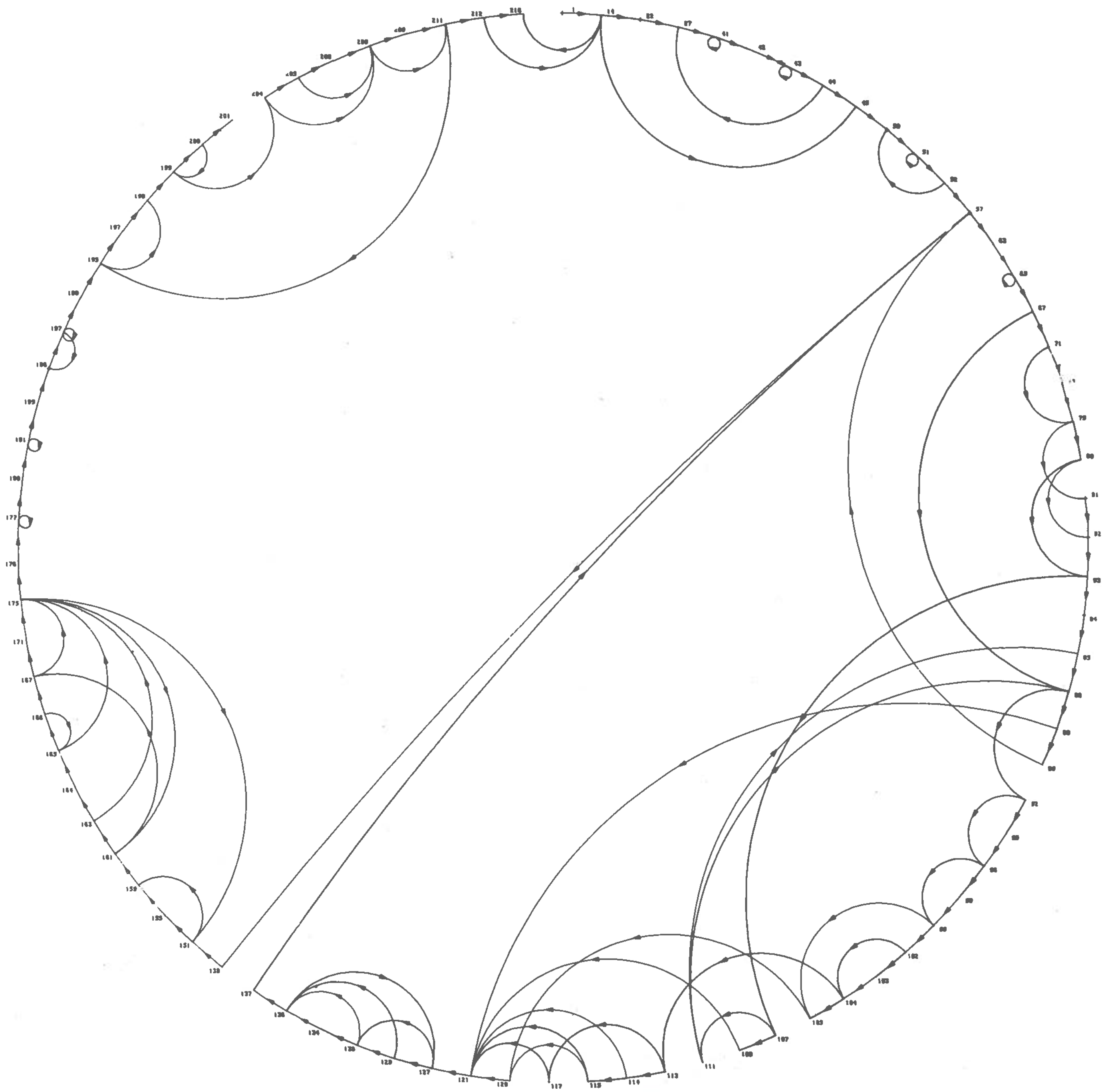


Fig. 11

Compared with conventional flow charts, which describe processes in terms of appropriately connected circles and boxes, a more recently devised format gives a better overview of the structure of a complex computer program. The example is for a program called "TASK", created by the engineering firm Proctor & Redfern, and shows how the 216 elements of the program are interrelated. The new format offers the added advantage of allowing the flow charts to be drawn automatically on digital plotters without any difficulties.

programs as they are needed, to be run on remote terminals. The savings in salaries and equipment costs would likely far outweigh the costs of time-sharing. At the same time, the development of a unique in-house capability in the interactive use of computers might result in unexpected competitive advantages in the firm's primary area of competence.

The search for an optimum balance in the mix of assembler languages, problem-oriented and higher level languages can never be brought to a permanent conclusion. Not only will needs change but advances in hardware and software development will eventually render both equipment and programs obsolete and necessitate a periodic reassessment of established computer uses.

Computer equipment – the staging of its introduction

At any point in a firm's operations, there exists an optimum theoretical level of computer use. Decisions to buy or lease computer equipment have to be made in major increments, however, and often involve major financial and manpower commitments. The objective should be to plan computer use in a way that matches acquisitions closely with data processing needs and with the organization's program-handling capacity. In practice, some phases will of course still be characterized by excess capacity, and others by excess load on the system. Computerization thus is never a smooth process in which slight adjustments can accommodate any evolving changes in requirements, nor one that can be reduced to a single step without causing disruptions severe enough to have potentially fatal consequences for the organization affected.

THE THRESHOLD APPROACH TO COMPUTERIZATION

In establishing the basic stages of computerization, the major considerations must be those of equipment increments, staff and the larger environment within which any such system must function. The latter covers many aspects of corporate planning, which can only be touched on here, such as the scale of operation and the financial climate within which decisions are reached, and also relates to external factors, the most important being the accessibility of external data banks.

DATA BANKS

Computers have revolutionized the collection, management and use of information, by subverting the value of written records and replacing them with data stored in binary form. For the first time, they allow information to be stored electronically and processed automatically. Generated at an increasing rate for many years, such data continue to be "deposited" in electronic data banks that are growing steadily both in number and size. Many of them belong to individual computer users and relate to their corporate or individual interests. A more important category of data banks, however, has been and is being created by the public sector. While at present only a few of them are open for general use, it is more than probable that more of them will become accessible.

The trend, therefore, is to the gradual establishment of a public banking system in which fresh data are deposited constantly and from which blocks of data can be "withdrawn" at a nominal cost. In such a system, a central role will obviously be played by government institutions like Statistics Canada which already releases data in binary form to interested users. A first result is the possibility of having computer-drawn demographic maps prepared from computer tapes provided by government departments (Fig. 12). The availability of serial survey data from federal or provincial sources would open similar opportunities for the custom-preparation of computer-drawn topographical maps. With cut and fill programs operating on the same data base, it would obviously be useful in the initial stages of large engineering projects. Another example is data obtained from remote sensing of earth satellites which could provide the basis for the impact zoning of land by regional and municipal governments while allowing equal access to basic information, to interested citizen groups and developers. In addition, municipal data banks might be accessible to obtain geocoded information such as existing lot sizes, land ownership, building setback requirements and service locations, at a command on a keyboard instead of through the present tedious routines in registry offices and local building departments.

Data of increasing importance in project planning and design are those relating to the life styles of people living in an area or expected to use planned buildings or facilities. This may require the establishment of new data banks for use by both lay and professional planners. Construction cost information, instead of being published in traditional printed form, may become available in constantly updated form from a central data bank that may be connected to the existing construction information system. In every such case, access to the information may be in one of two forms: by obtaining the data on computer tape, or by obtaining it on a computer terminal directly from the data bank.

TWO ALTERNATIVE APPROACHES TO COMPUTER USE

The two different ways of making use of data stored in central data banks are characteristic of the two distinct alternative approaches to computer use. The "terminal approach", depending on links to both computers and data banks, emphasizes access to information and remote computing capability. The "in-house approach", by contrast, emphasizes operational self-sufficiency. But when seen in the overall context of a gradual increase in the use of computers throughout the construction industry, either one of the two approaches appears to be no more than transitional.

As a result of the broadening range of possible computer applications, the dependence on more terminals will grow too costly for most users, suggesting the need for installation of some supplementary in-house computing capability, probably linked to the existing terminals. On the other hand,

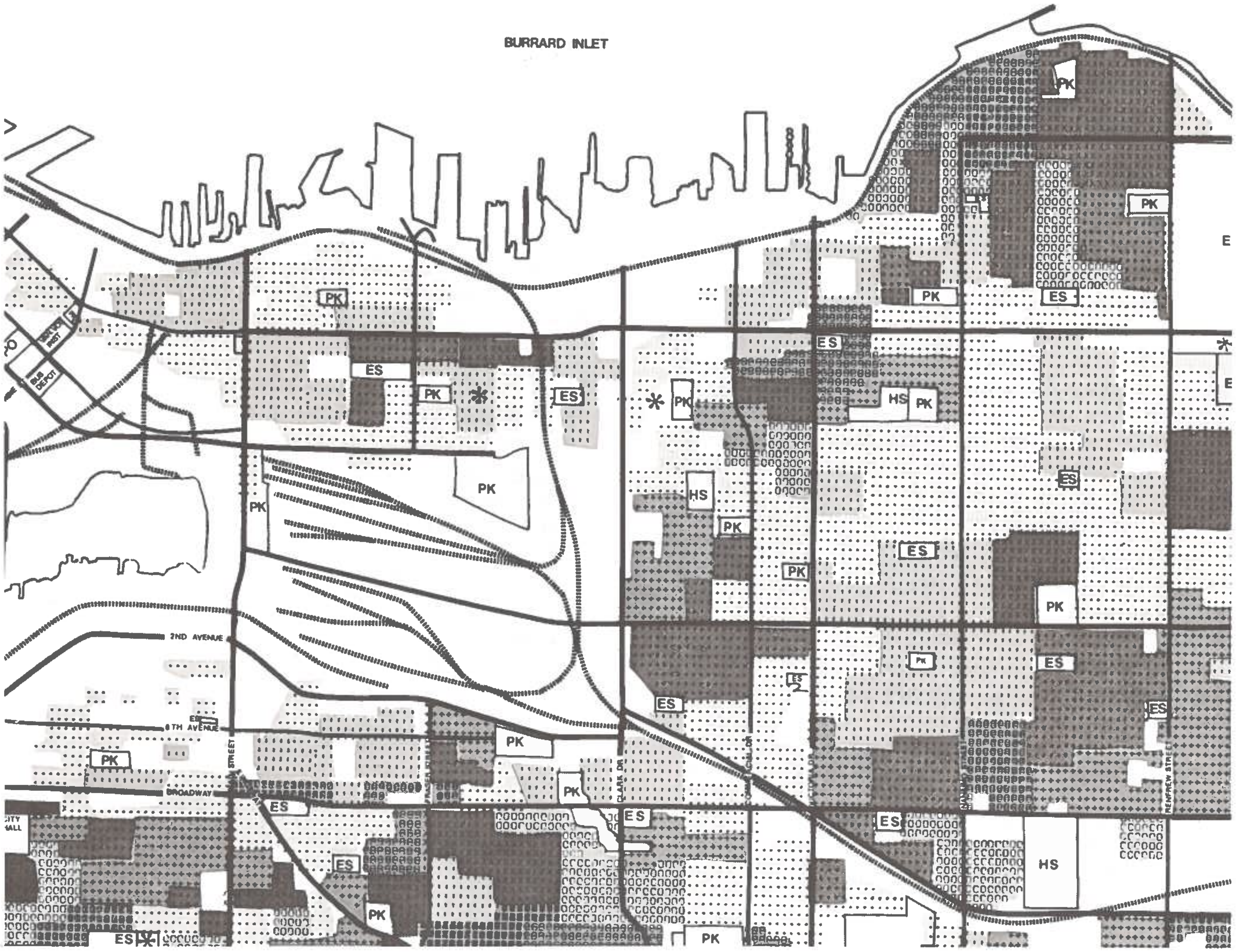


Fig. 12

Computer-generated maps, based on available census data and displaying any desired demographic information, have become available commercially and can be very useful in the planning of new projects.

Source: International Urban Analysis Corporation, Vancouver, B.C.

even the largest in-house computer systems will increasingly have to depend on direct access to an expanding system of accessible data banks.

The two streams will merge once computer use in the construction industry approaches a state of maturity. At that point, in-house computers of all sizes, from microcomputers to large main-frame computers, will be found dispersed throughout all sectors of the industry and will be connected in every case to a variety of public and private data banks as well as, in all but exceptional circumstances, to large time-sharing systems in order to reduce peak loads on the in-house system.

THE USES AND LIMITATIONS OF IN-HOUSE COMPUTERS

In-house computers come in all sizes, from programmable calculators and microcomputers, through minis, to large integrated systems capable of serving numerous terminals. Size is relative, however, and must be viewed in the context of the scale of a firm's operations. To a large manufacturing corporation serving the construction industry, a decision to create an automated engineering design and drafting system thus may involve a smaller share of available resources than the acquisition of a microcomputer does to a small consulting firm. In either case, however, investment decisions and manpower commitments must be made on the basis of a rational analysis of the advantages to be gained from computerization and of the probable costs.

There used to be a rule of thumb which suggested that, in estimating the cost of computer operation, "machine dollars" be matched with "people dollars". It meant that to obtain optimum results, the costs of owning a certain range of computer hardware should be doubled to obtain a figure that would roughly represent the total cost of a successful computer operation. With some equipment steadily dropping in price and salaries rising, this rule obviously must be applied with increasing caution. Even though the cost of writing programs and preparing conventional computer input will thus continue to rise, new computer uses will benefit from past experience and the advancement of techniques and be more effective in raising productivity. Meanwhile, the need for card punching should decrease as data available directly from existing data banks accumulate.

The problem of predicting cost-effectiveness is particularly troublesome when the initial acquisition of a computer must be justified. The performance of a computer is fairly predictable if it is bought or leased for specific tasks in a given environment for which tested programs are available. Examples are computer applications in accounting, job control, cost estimating and engineering calculations. Alternatively, a computer may be looked upon as a speculative investment, acquired either to provide specialized services or to perform in-house services required to render the firm generally more competitive (Fig. 13).

Whatever the initial motive for acquiring in-house computing capability — increased profits from an existing business, the potential for selling services, or an improved competitive position — its ready availability will normally lead to a wider range of applications than originally planned. As a result, there will be a tendency to add peripheral equipment and core storage capacity. Where the operation of the computer is entrusted to a separate department, such expansion will of course be accompanied by requirements for more staff and, inevitably, the question of whether or not to "trade up" to a larger computer.

This raises the question of the optimum size for in-house computers. Perhaps a parallel situation in the electrification of industry ought to be recalled. In that case, the early practice was to drive all the machines in a plant from a central power source with the help of transmission belts; it was only when mass-produced electric motors became available that machines could be driven individually as they are now. The advent of microcomputers may have a similar impact on the direction of computer use. Rather than increase the size of central in-house systems, mass-produced microcomputers, adapted to specialized purposes and placed at the disposal of individual professionals, may be acquired in their place. Linked to large central computer utilities in the way electric motors are fed from central power plants, microcomputers could still deal with major computing and data processing tasks on a remote time-sharing basis.

THE USES AND LIMITATIONS OF TIME-SHARING TERMINALS

Renting a time-sharing computer terminal removes the need for a commitment to computerization that is inherent in the installation of an in-house computer. The significant difference between the two options thus lies less in the performance potential of one or the other, than in the financial implications of the choice. While ownership of a computer encourages maximum use to be made of the equipment, the rental and time charges for terminals tend to restrict computer use to the specific applications foreseen in the budget.

Time-sharing nevertheless offers advantages that cannot be matched by in-house computers. One of these is direct access to central data banks from which information on construction materials, specification clauses, demography, etc., may be retrieved instantly. A second advantage relates to the possibility of using proprietary programs stored in the computer that might not otherwise be available. A third major benefit is the ability to apply the practically unlimited power of a large computer system to a specific problem.

Coupled with these advantages are certain real and potential drawbacks. The latter relate mainly to security aspects of centralized computer operations which are out of the control of the subscriber to a time-sharing service. Real disadvantages become apparent on the not necessarily infrequent occasions when a time-sharing system is overloaded or suffers temporary breakdowns. In an in-house situation, such difficulties are obviously easier to deal with because priorities within a firm can be more readily established than among subscribers to a service. In a decentralized in-house system, problems of this kind become altogether insignificant.

Other problems sometimes originate in the telephone lines that transmit data from computer to terminal. The quality of remote plotter output thus may suffer from transmission inadequacies rather than, as may at first appear, from faults in the plotter or the computer program. To avoid such difficulties, output from the central computer is best fed from tape into a smaller computer dedicated to the operation of the plotter.

No such ready solution is available when it comes to solving the problems of operating interactive graphic display terminals. The images appearing on the CRTs used for this purpose must be constantly refreshed and instantly updated in accordance with the latest lightpen-input. This requires a stream of instructions from computer to terminal that cannot possibly be accommodated on normal telephone lines. Interactive graphic devices, therefore, need to be backed up by a computer dedicated to its operation and cannot be run solely on a time-sharing basis. As a consequence, the use of time-sharing terminals limits graphic displays to stationary images on storage tubes or generated from a local memory device, neither of which allows instant man-machine interaction.

STAGING THE INTRODUCTION OF PERIPHERAL EQUIPMENT

Different items of peripheral equipment make different demands on the computer system they serve, and on the users of such systems. The introduction of peripheral computer equipment, therefore, cannot be considered in isolation. Instead, its staging must be related to the way com-

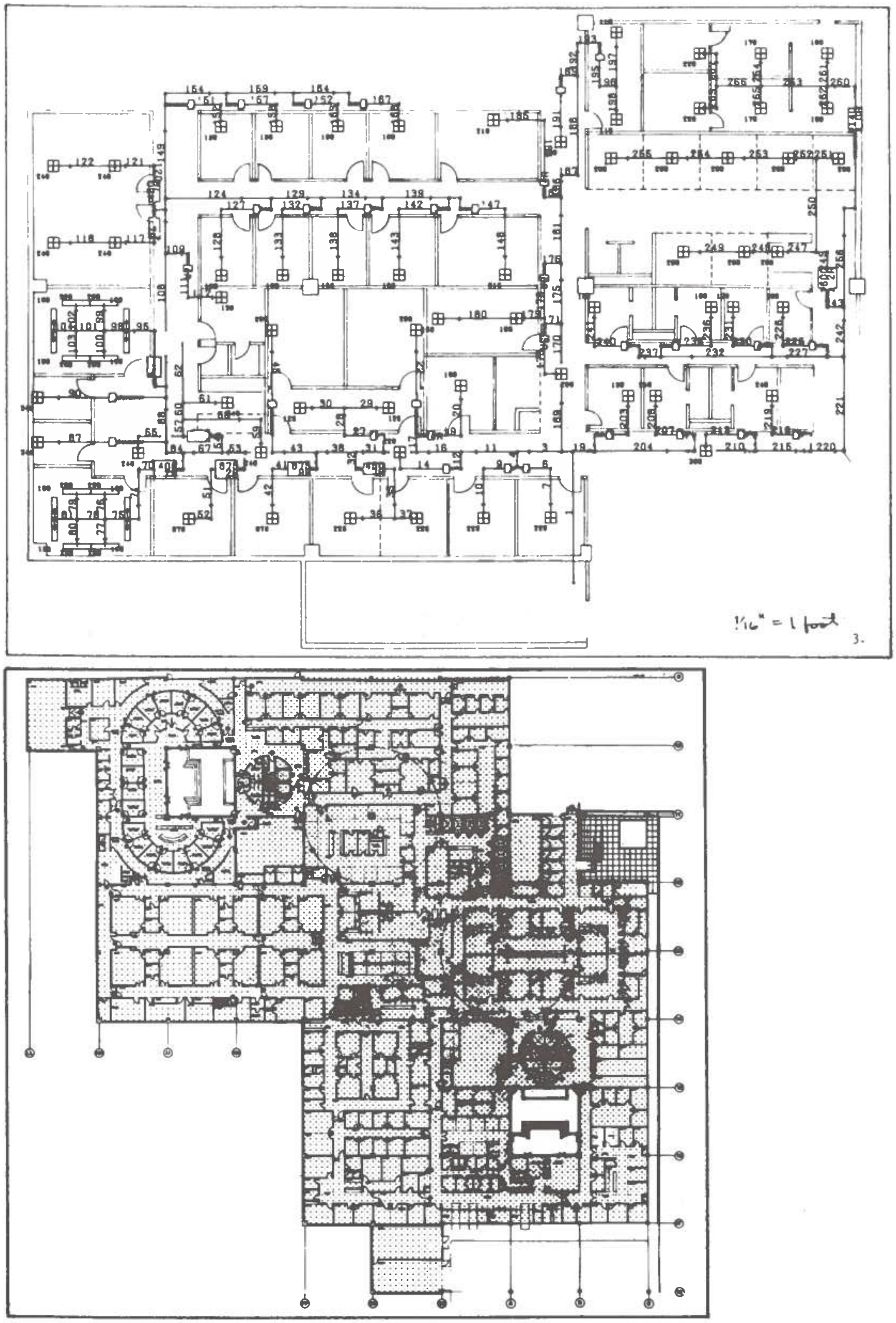


Fig. 13

A specialized service that will undoubtedly gain in popularity is that of computerized drafting based on architects' or engineers' sketches. In the case of Computer Service, Inc. in Chicago, a "Duct, Piping, Design and Drafting Program", a "Frame Shop Drawing Program", and an "Architectural Drawing System" — for the preparation of working drawings, taking off quantities, producing door, finish and hardware schedules, and preparing complete area calculations — are combined to offer a comprehensive drafting service to the construction industry.

Source: Computer Service, Inc., Chicago, Ill.

puter use evolves in the specific organizational context. Traditionally, this evolution falls roughly into the following pattern:

Phase 1: Work previously done in-house is transferred to outside specialists using computers. In the construction industry, this has happened in areas such as cost accounting, quantity surveying, project scheduling, statistical analysis and specification writing. The only contact the original firm has with the computer is having to prepare information in a format that closely relates to the format of computer input.

Phase 2: A first threshold is reached when it is recognized that there is enough work suitable for computer use to justify the rental of at least one time-sharing terminal. Alternatively (or simultaneously), technical or management problems may be encountered that cannot be dealt with effectively without the help of computers and lead to a tentative involvement in computer programming.

Phase 3: A second threshold is reached when terminal operations and programming activities have grown to a level at which a small in-house computer can be operated at less cost. Usually, this involves formation of a separate data processing group or department.

From this point onward, growth will tend to follow Parkinson's Law and involve the gradual acquisition of peripheral equipment, the expansion of staff and the computer's capacity to better support and control the equipment. An often attractive alternative to Phase 3, therefore, has been the rental of added time-sharing terminals that serve specific functions. To carry out occasional but major computing or data processing jobs, a combined card-reader/line printer connected to a remote time-sharing system may thus involve much less overhead than the operation of an in-house computer with comparable peripheral equipment. The advent of microcomputers has opened another path to computerization — that of bypassing the rental of computer terminals:

Phase 2A: A first threshold is reached when it is recognized that there is enough work suitable for computer use to justify acquisition of a microcomputer. This leads to a commitment to develop the decentralized in-house programming capability necessary to enlist the aid of the computer in a widening range of technical and management problems.

Phase 3A: A second threshold is reached when one or more of the microcomputers require an optional direct link to a central data bank and a large time-sharing system to handle special tasks.

The significant difference of this alternative path to computerization is that it need not involve the formation of additional departments within an organization. Instead, microcomputers and microcomputer-driven peripherals remain under the direct control of individual users and user groups, with data processing departments needed in large organizations only to support and co-ordinate the use of the microcomputers and to operate whatever central batch-processing that may still be required.

THE CONCEPT OF INTELLIGENT TERMINALS

In spite of their differences, the two alternative paths to computerization — one involving increasingly more elaborate terminals; the other the linking of in-house computers to large remote installations — will arrive at a point where in-house computing capability everywhere is linked to a system of data banks and large computers. In-house systems then take on the characteristics of intelligent terminals which may be controlled by special departments or directly by their users depending on the organizational structure of a particular firm.

If this is indeed to be the outcome of the trends, the question arises what benefits could be derived from accelerating the present development process. Specifically, it may be possible to anticipate future requirements and to design optimal terminal configurations for specific tasks, rather than, as in the past, trying to adapt equipment designed to appeal to as broad a market as possible to the special needs of the construction industry. Development work in this direction is currently under way at the Federal Department of Public Works in Ottawa (Fig. 14).

Two separate factors should favour such efforts. One is the construction industry's state of relative underdevelopment. While in other industries many paths are blocked to development by established programs, personnel, and routines, the construction industry is comparatively untouched by advanced methods and should therefore prove more open than other sectors of the economy to innovative processes and devices with an established performance potential. The second favourable factor relates to the impending arrival of a new generation in the work force that has been brought up on the concept of computer use and is familiar with programming requirements. Feelings of fear and hostility should therefore play a gradually declining role in people's attitudes to the computerization of routine mental tasks.

Computers will inevitably play a larger role in the construction industry if only because planning requirements will become increasingly more sophisticated. Two examples are the growing demand for environmental impact studies as part of the normal project planning process, and the need for tighter scheduling of more capital-intensive construction processes. Optimum computer use in such areas will help achieve maximum productivity gains. This will call for the increased specialization both of individuals and firms, however, and may ultimately also involve a restructuring of many aspects of the construction industry.

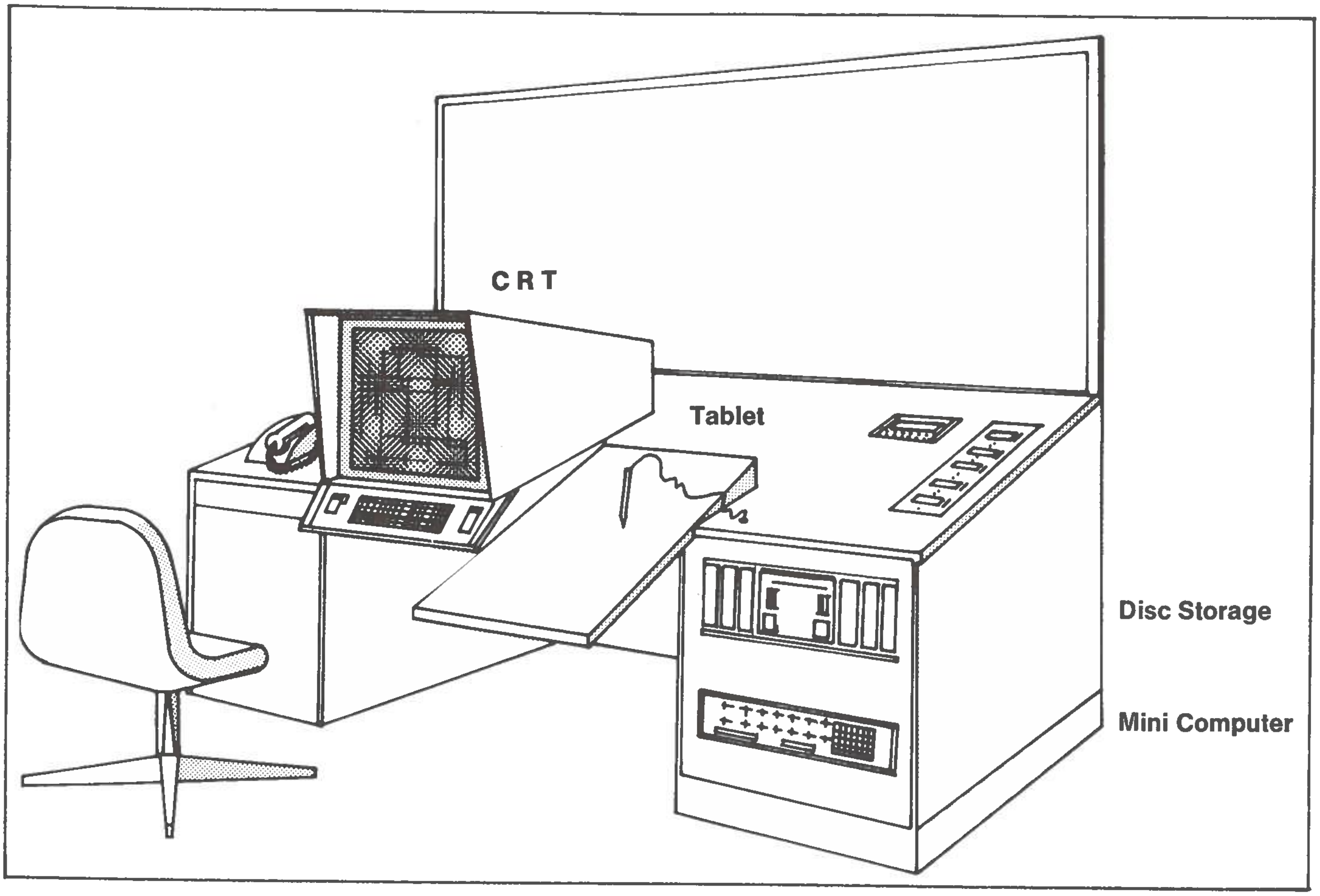


Fig. 14

As envisaged by the federal government's Department of Public Works, design stations of the kind illustrated will be linked to central computers and databanks. A part of a computer-aided design system that is under development, they are expected to contribute to an increase in the effectiveness and productivity of architects and engineers.

FURTHER INFORMATION

The aim of this report is to introduce readers familiar with construction industry problems to the idea of using computers to an increasing extent, by giving an overview of the state of the art and the potential of computer application. Hopefully, readers will be encouraged to probe deeper into those aspects of computer use that are of special interest to them. There are several ways in which this can be achieved:

Direct Inquiries: Considerable amounts of information can be obtained through direct contacts with representatives of computer equipment manufacturers, companies offering time-sharing and consulting services, and with independent management and computer consultants.

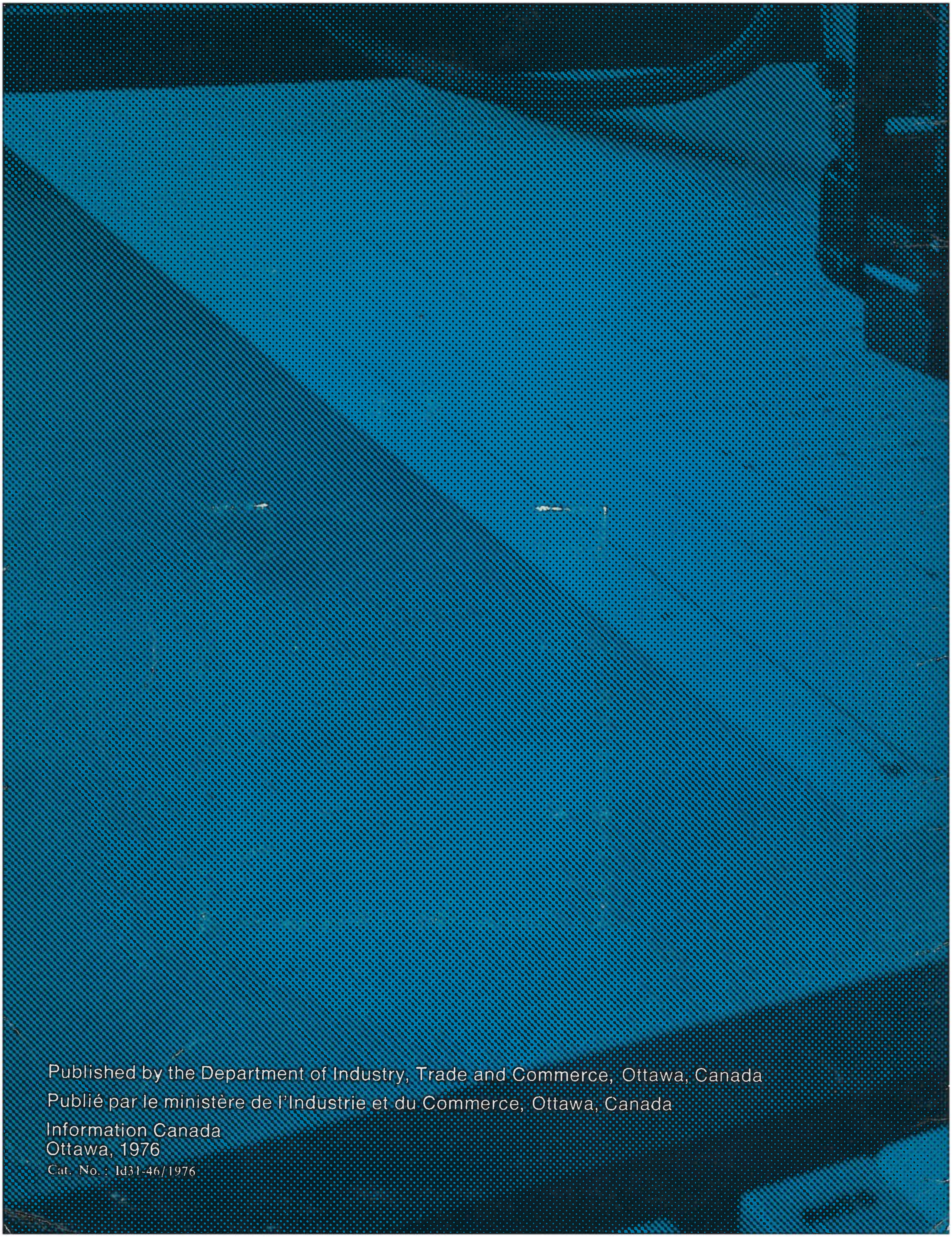
Literature: Finding one's way through the vast literature relating to computers and their uses is a difficult undertaking, especially since much of the relevant information is found in books and magazine articles on engineering, management science, design methodology, etc. A comprehensive list of programs and bibliography on computer literature relating to architecture and some aspects of construction has been published by the Environmental Design Research Center in Boston, Massachusetts. Lists and literature in this field become quickly obsolete, however. Actual and potential computer users thus may be better served by one or more of the numerous magazines covering the computer and data processing field. Among dozens of periodicals, the monthlies Canadian Data Systems (MacLean-Hunter, Toronto) and Datamation (F. D. Thompson Publications, Greenwich, Conn.), and the weekly Computer World (Newton, Mass.), probably have the widest circulation in Canada and the United States.

Associations and User Groups: Usually the most valuable information is obtained from other computer users. The best way to establish contacts is through attendance at relevant seminars, conventions and forums. Participation in associations and computer user groups sometimes offer the added advantage of access to programs and lists of available programs. Examples are:

Canadian Information Processing Society (CIPS) —with headquarters in Toronto, the society organizes local and national meetings, publishes a magazine, carries out surveys, etc.

Design Methods Group — based in California, it publishes the DMG/DRS Journal dealing with emerging design and planning methodologies.

APEC (Automated Procedures for Engineering Consultants) and CEPA (Civil Engineering Program Applications) — user groups based in the United States open to firms interested in developing, distributing and supporting practice-oriented computer programs.



Published by the Department of Industry, Trade and Commerce, Ottawa, Canada
Publié par le ministère de l'Industrie et du Commerce, Ottawa, Canada
Information Canada
Ottawa, 1976
Cat. No.: Id31-46/1976