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Computer Supported Information Interchange for Construction Projects

Echange informatisé des données dans les projets de construction

Ein computergestützter Informationsaustausch für Bauprojekte

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SUMMARY

The use of computer-aided design (CAD) systems within the UK construction industry is examined to determine how they might aid the construction management role. A specification is proposed for a system which will integrate time, cost and operational data into the overall working arrangements of a CAD system. The use of small computers as a basis for such a system is examined together with their inherent limitations.

RÉSUMÉ

L'emploi des systèmes de conception assistée par ordinateur (CAO) dans l'industrie de la construction en Grande-Bretagne est examiné afin d'améliorer la direction des projets. Le système proposé incorporerait le temps, le coût et les données opérationnelles dans les dispositions générales du système CAO. L'utilisation de petits ordinateurs est envisagée pour de tels systèmes et leurs limitations sont traitées.

ZUSAMMENFASSUNG

Es wird der Einsatz von CAD-Systemen innerhalb der britischen Bauindustrie untersucht, um zu bestimmen, wie diese die Bauleitungstätigkeit unterstützen können. Ein System wird vorgestellt, das Zeit, Kosten und operationale Daten in die allgemeinen Arbeitsabläufe eines CAD-Systems integriert. Die Einsatzmöglichkeiten von Klein-Computern und die ihnen innewohnenden Beschränkungen werden untersucht.

1. INTRODUCTION

In the UK construction industry, the acceptance of CAD techniques has been slow and limited, almost entirely, to those organisations with a significant responsibility for producing detailed drawings. As a result, computer-aided design (CAD) systems are regarded generally as a means for automating drafting, even though they have been shown to offer distinct opportunities for both design management and construction management [1]. It is suggested this preoccupation with mechanising manual methods overlooks the possibility of CAD systems being used as the focal point for unifying all information on a construction project, perhaps through a design-oriented or project-oriented data base. An objective of this paper is, therefore, to present a statement on the current application of CAD systems within the industry; another objective is to determine the probable impact on the industry of developments in CAD techniques over the next five years. These objectives are realised through the findings of thirty-five case studies, conducted as part of a Science and Engineering Research Council funded project entitled "A computer supported information interchange for construction projects". A number of possible applications involving the wider use of CAD techniques are discussed, particularly in the handling of information of benefit to construction management. This paper also examines the proposition that the technology necessary to handle management information is available now; that there is sufficient expertise to produce working systems; but that traditional methods of working and, more especially, the barriers between the professions almost negate innovation.

2. CAD USE IN THE UK

2.1 Historical perspective

Today's use of CAD systems within the UK owes much to the successes achieved in the mid 1970's through developments which were supported by large scale public sector construction programmes. Examples of these were the systems for the Oxford Regional Health Authority, namely the Oxford System (OXSYS) which led to Applied Research of Cambridge's BDS and GDS systems; Clwyd County Council's system, CARBS which led to its commercial offspring, Acropolis by Building Design Partnership (BDP); and the Scottish Special Housing Association (SSHA) systems which have been carried through into work being undertaken currently by EdCAAD (University of Edinburgh). A close evaluation of most of these CAD systems reveals a situation which, at the time, must have seemed difficult to justify by the single measure of cost. However, these systems were developed by public sector bodies, in parallel with various building systems, and were intended to support full scale design, in addition to drafting. Conversely, the majority of users in the private sector introduced CAD systems to automate drawing production and expected them to have little or no impact upon existing infrastructures. It was not until the early part of this decade that acceptance of the benefits of CAD techniques penetrated into working practices. Much of the apparent delay in the use of CAD systems can be attributed to the gap between technically feasible solutions and commercially acceptable ones. A cost/pay-back threshold has now been reached, due primarily to a significant fall in hardware costs and the refinement of software tools. It is suggested that most of the enabling CAD technology is available now, although many potential users are unaware of the benefits on offer. A significant obstacle is that of education and training in the use of this technology.

2.2 Research findings

2.2.1 Reasons for using CAD systems

Often the cost of a CAD system was justified by the award of a large project, particularly where standardisation or repetition was significant. In one case a CAD system was introduced in an attempt to enable the organisation to remain competitive. In another case, the main purpose of introducing a CAD system was to re-organise the design process so that construction and other production information could be considered early in the design phase when major decisions regarding cost were made. The system used here was able to analyse cost and resource data, where these had been introduced. In a small number of other cases, it was discovered that the real needs of the organisation had not been understood fully and as a consequence, users had to accept limitations in the computer system. For instance, the CAD system was expected to speed up existing design practices without affecting them in any way.

2.2.2 Trials and benchmark testing

The decision to buy a CAD system had been taken very seriously by most organisations. There were instances where extensive pilot studies had been undertaken, with CAD system vendors competing in trials sometimes lasting up to twelve months. It was common for benchmark tests to be imposed to determine the speed of drawing production and other criteria were adopted by prospective purchasers in their search for a suitable system. Of these, the more significant ones confirmed the basic requirement for systems to produce drawings more rapidly than by manual methods and that the cost of the system would have to be justified by savings in the cost of producing drawings.

2.2.3 In-house developed CAD systems

Some CAD systems or parts thereof had been developed for individual clients and then adapted for general use elsewhere, following a computer industry trend of using commercial sites to undertake development and performance testing. A few users had attempted to develop major software modules and even their own complete systems, but had failed. Development time and costs had been found to be prohibitive. This confirms the view that the more commercially successful CAD systems are generalised and not designed specifically for construction industry applications.

2.2.4 Software issues

A problem experienced by many users was in attempting to integrate third party software into the main (CAD) system. This sometimes resulted in extensive and expensive development work, often without the full co-operation of the CAD system vendor. A significant number of users had undertaken some program generation themselves to provide a CAD system which was more in keeping with their own practices. Some users admitted to expecting to undertake some software development themselves. Where in-house software had been developed, this was used to 'plug the gaps' in the facilities offered by the CAD system.

2.2.5 Upgrade paths and maintenance

The high capital cost of CAD software was found to be matched by high recurrent charges, imposed by the vendors, for continuing support and maintenance. Whilst it was acknowledged that existing investments in software and data should be protected, the cost of ensuring an upgrade path over the short to medium term was sometimes greater than the initial capital cost. However, the feeling was that updates of software were invaluable and that the recurrent costs were at least offset by the benefit of having the CAD system grow with the organisation.

2.2.6 Operating and communications issues

The high cost of most CAD systems, in terms of both capital and running costs, had to be matched by high levels of utilisation. This had been achieved by some users introducing shift working, whilst others offered a bureau service. Elsewhere, demand exceeded the availability of the system, such that time had to be allocated amongst working groups or teams. It was also highly likely that different design consultants on the same project were using different CAD systems, if they were using them at all. It was suggested that the special and diverse needs of each user were reflected in their particular choice of system. However, there was some evidence of an exchange of data (via magnetic tapes) between design consultants engaged upon the same project where the CAD systems were of the same type. For those with more remote workstations, as in the case of a regional office, a British Telecom Kilostream line was an increasingly popular means for communicating with the central processor. The linking of a number of CAD workstations via a local area network (LAN) was an emerging trend in organisations which were heavy users of CAD systems.

2.2.7 Hardware issues

Monochrome displays were found to dominate, with colour displays regarded as a low priority because of their much lower resolution. The high comparative cost of colour displays was also a factor. The use of keyboards was thought of in some instances to be the most accurate means of data entry and was preferred by many users to more visual methods such as digitising tablets. It was found that the more experienced users became, the more they were able to construct macro commands and user routines in high level languages such that the speed of drawing was improved greatly. Most users found it necessary to increase the capacity of their systems, often within a year of the initial installation. This trend was so prevalent that it is suggested some CAD system vendors sell under-powered hardware deliberately, in order to keep the initial purchase price down, in the knowledge that upgrades can be accommodated easily. The use of non-standard hardware by a number of vendors and an inability to run third party software has been a disturbing feature of systems in the past. However, with an ever increasing number of vendors competing for a share of the market, the situation has improved considerably.

2.2.8 Dis-integration of systems

It was found that some users had made positive decisions not to integrate all computer systems within their organisation, but rather to continue with separate, independent systems that could be dedicated to specific tasks. This was especially true of the retention of separate systems for word processing. In one case, the CAD system down-loaded schedules to a word processor rather than edit them directly. Generally, CAD systems were found to be incapable of supporting other work, although some organisations had attempted to integrate separate design functions into a single CAD system and had been moderately successful.

The idealised view of a system supporting the needs of all members of the design and construction team is fraught with practical problems. There are good reasons why a total design or project data base is not only difficult to implement but also to control. This is due largely to the demand for up-to-date data together with automatically enforced consistency and co-ordination. The dis-integrated model is offered as a compromise to the fully integrated system and was proposed originally by Richens [2]. A data base which is available to all disciplines constantly is incapable of maintaining consistency, therefore, a compromise is needed. In practice, restrictions would be imposed upon the relationships between different geometric entities such that sub-models of the design were controlled by individual disciplines, each with its own data. This is similar in concept to each discipline working with its own computer and means that the individual user has to understand no more of the total system than is relevant to the task in hand.

2.2.9 Microcomputer-based systems

The proliferation of microcomputer-based CAD systems is introducing many organisations to CAD techniques for the first time. However, expectations have tended to rise well above the actual performance of these systems, because many users are unaware of the limitations in them. In one case a microcomputer-based 2-D drafting tool was linked to the main CAD system. This was used for digitising the details of property surveys which were then transferred to the main CAD system for entering into the drawings library. Here, the microcomputer was used mainly as an 'intelligent' terminal to prepare data for input to the larger system.

2-D drafting is the extent of many microcomputer-based software packages with some little more than sketchpads with no knowledge of what the symbols mean nor the rules that might well govern the real world objects they represent. The availability of microcomputer-based 3-D modelling systems is limited, mainly because of their inability to offer the range of features which makes 3-D such an attractive proposition on larger systems. For instance, on-screen manipulation of 3-D models such as rotation, which opens up opportunities for visual simulation, is virtually impossible to perform on microcomputers, because of limitations in processing and display technology. Visual simulation could provide a most valuable means of scrutinising the construction implications of a proposed design. Hidden line removal is also a problem, in that the time taken to regenerate perspectives can be several hours. The building model shown as a wire-frame in Fig. 1 required the removal of ninety-seven thousand hidden lines and took approximately two and a half hours to accomplish on a 16 bit microcomputer.

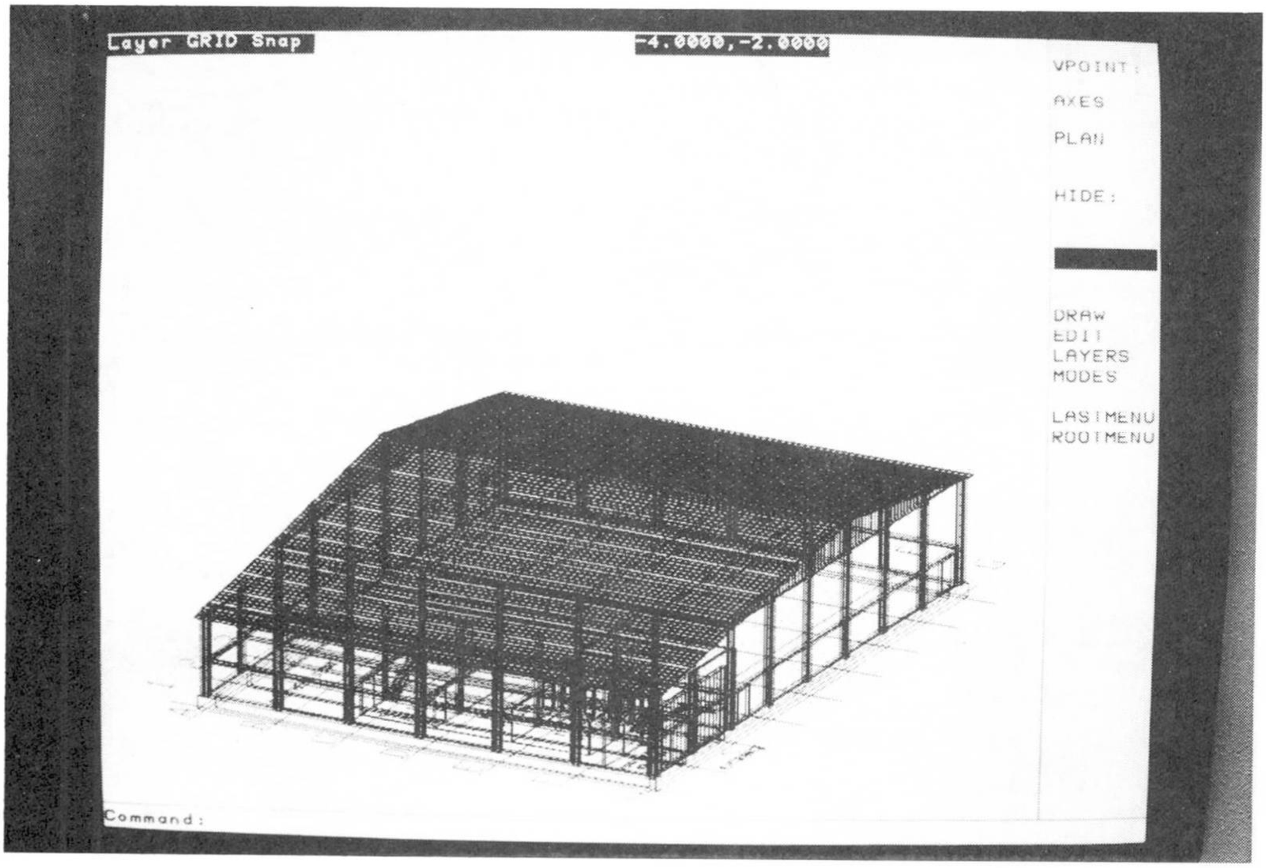

Fig.1 3-D wire-frame building model

There is little doubt that, at present, CAD systems on mainframes and minicomputers are capable of achieving significantly more than their microcomputer counterparts. This is especially true of the limitations of microcomputers to facilitate 3-D modelling in a fast and presentable manner, and to process a range of non-geometric data concurrently.

2.2.10 Design methods

A problem which designers face, when using component-based systems, is the creation of the components. It is often difficult to know where one is working within the component/sub-component relationship. Problems arise when different personnel are used to update drawings, as it is not always known how assemblies have been created. Work in 2-D was found to dominate almost to the complete exclusion of 3-D. Moreover, there appeared to be a great reluctance towards working in anything other than 2-D. It is suggested this is attributable to traditional design practices, and that the mere provision of inexpensive 3-D modelling systems will not force a move away from practices instilled in the minds of the majority of designers. In the few cases where 3-D was used, it was intended primarily as a marketing aid and for visualisation purposes only. The failure to use 3-D modelling systems can also be blamed upon the heavy demands for computer processing and display technology which must be translated into real costs for upgraded equipment.

2.2.11 2-D drafting vs 3-D modelling

The issue of whether 2-D orthographic images or a 3-D model of the building is held in the computer is especially important. From a drafting point of view, there is a marked disadvantage in the simple 2-D approach. The different views of a building space (plan, elevation and section) or component assembly are unconnected and, therefore, a variation in one is not automatically made to the other(s). This represents a fundamental flaw in the 'electronic drafting' of a 3-D object such as a building. At one end of the communication's spectrum is a need to provide the client with an appreciation of the building's form and at the other end, there is a need to provide the building operative with component assembly details. It is imperative, therefore, that CAD systems for building design should be of the 3-D modelling variety to enable drawings to be produced on demand to suit individual needs.

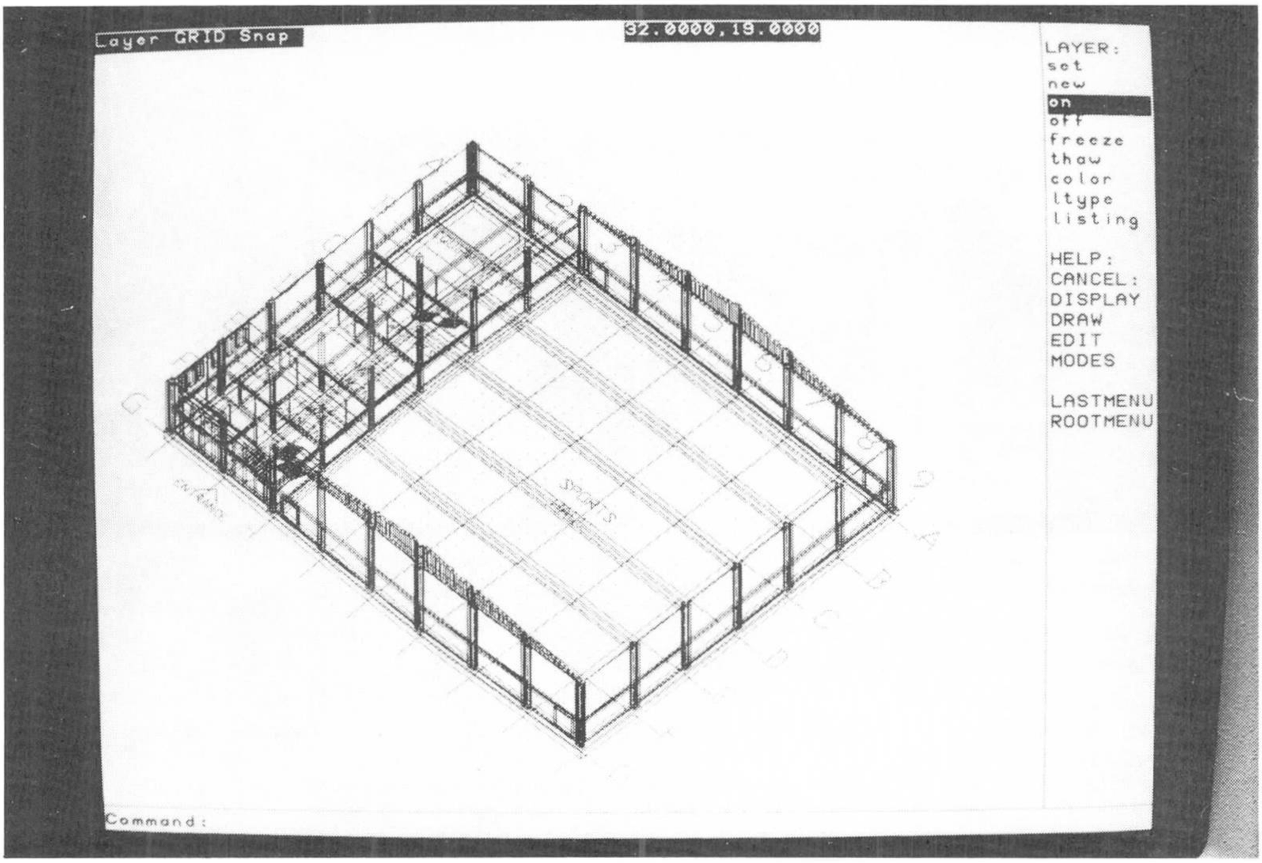

Fig.2 3-D wire-frame building model - roof detail removed

Fig.2 illustrates a 3-D wire-frame model of the building shown originally in Fig.1 and was created with AutoCAD software on a 16 bit microcomputer. This system offers an inexpensive, easy way of introducing CAD techniques, providing the limitations are appreciated. The production of drawings 'on demand' is illustrated in Fig.3 where an elevation is generated from the original 3-D wire-frame model shown above.

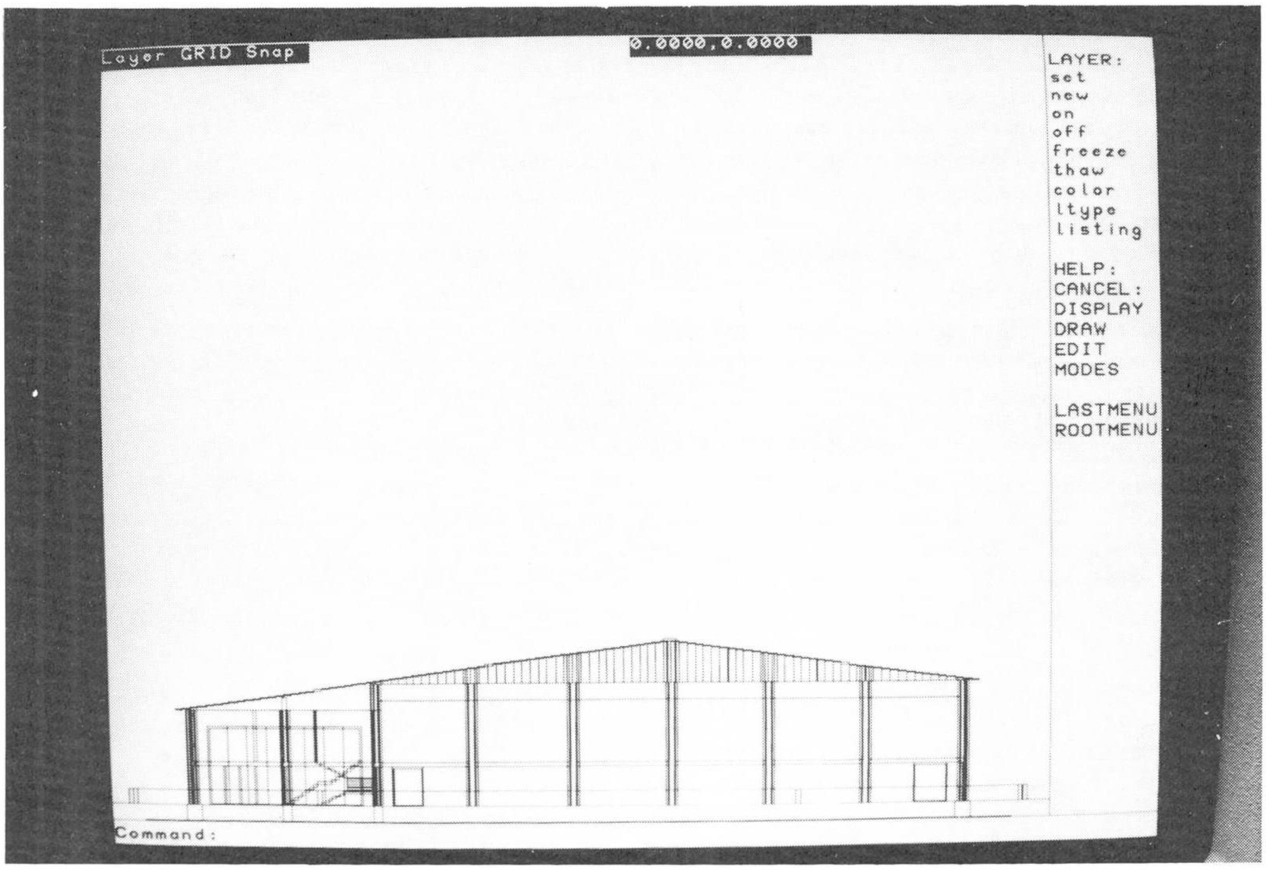

Fig.3 The generation of 2-D drawings 'on demand'

A 3-D modelling system such as ACROPOLIS, running presently on minicomputers and stand alone workstations, offers a suitable approach to the 3-D modelling concept and highlights significant limitations in many of the microcomputer-based systems. The 3-D model is defined at the outset and all data, both geometric and non-geometric, are ascribed to it, rather than unconnected 2-D views. 2-D drafting systems that connect to other 3-D facilities (eg. AutoCAD) do not offer the same degree of model 'wholeness' that would be expected with a true 3-D modelling system. Experience has shown that once the system has been mastered by the user, 3-D geometric data input is no more difficult than 2-D input and far more useful to later evaluation exercises.

2.2.12 Data base structures and graphical attributes

The extent to which CAD systems can be used to provide information, other than that expressed graphically, is limited by the amount of non-graphical data that can be handled. In one case specification information was placed on the drawing to avoid searching the system's data base which was particularly restrictive. The amount of management information (eg. resource measurement) that is possible is dependent upon the way non-graphical data are related to the graphical data and then manipulated to produce schedules and reports. The hierarchical nature of most CAD data base management systems makes such manipulation difficult, because of their inherent lack of flexibility. The suitability of relational data bases, however, can be emphasised by their potential to maintain a single, coherent information-base representing all facets of a building. This information-base is defined currently by separate documents such as, drawings, specifications and bills of quantities, with each demanding different presentation requirements. Relational data base structures are especially suited to the needs of the design and construction team as they present data to the user in tabular form and allow subsequent changes to the data structures. Few relational data base management systems have been developed specifically for microcomputers, with the notable exceptions of dBase II/III. Many systems have been developed for mainframe computers, although ORACLE and RAPPORT have microcomputer versions running on IBM PC and certain compatible emulators. The main problems likely to be encountered with data base management systems on microcomputers are those of limited external storage capacity and available RAM. For instance, the drawings, attribute files and reports on one project could easily fill a 20 Mb hard disk. The limitations on memory size are even more restricting. Data base management systems can require as much memory as the CAD system and occasionally more.

It was found that minimal use was made of attribute facilities within data base management systems, when these were available. This was surprising in those cases where the organisation appeared, on the face of it, to have good cause to use such facilities. Reasons were varied, although one fairly common finding was the time-consuming way in which libraries of components could be built-up. Standard component libraries were found to be little used and, where available commercially, were of limited value. In addition, some of the existing data base management systems were inadequate for storing large quantities of drawing information. This might well have been a direct result of the structure of the data base itself rather than the size or complexity of the drawings. The sizes of drawings, in terms of their computer storage requirement, were found to vary between 10 and 500 kb.

Building designs are often detailed using components from a data base. This components' data base has graphical and non-graphical (alphanumeric) sections, with the latter containing the attributes or properties of the components. In some systems, the attributes are restricted to a single word or code for each component; in others a large number of attributes can be attached to each component. However, data bases incorporated into many CAD systems are limited and a link to a more substantial data base management system may be required when the generation of non-graphical information is important. The principle of the attribute system is the same for 2-D and 3-D software. However, there is a problem of consolidation with 2-D systems, because components are counted on every drawing and, therefore, may be included several times. 2-D systems calculate areas, but only 3-D systems can calculate volumes. Unfortunately, neither system can be guaranteed to measure resources directly.

2.2.13 Bills of materials/quantities

A document which is common to many industries is a bill of materials and, therefore, its incorporation into the report generation facilities of some current CAD systems is an obvious development. For instance, details of where equipment might be found and the grouping of components by location, are an established feature of some CAD systems. However, the composition of bills of materials is considerably more straightforward than bills of quantities, which are virtually peculiar to the UK construction industry. One CAD system incorporating a bills of quantities system was found to be operating successfully on commercial projects for a major petroleum company. Considerable development work had been undertaken to incorporate a standard bills of quantities system into the working arrangements of a general drafting system. The result was held to be successful by the organisation, but was restricted to a standard range of designs.

Bills of quantities were also incorporated into some CAD systems many years ago. The OXSYS, HARNESS and SSHA systems incorporated a bills of quantities production feature. These systems were not available commercially and it is doubtful if they would have been financially viable. The problems associated with generating bills of quantities from CAD systems rest jointly with the method used to create the design and that used to classify the work. It is usual for systems of this type to be component-based, 3-D modelling systems which necessitate a significant departure from traditional design methods. In the private sector, it is difficult to see how designers would benefit directly from the additional work of such an approach.

2.2.14 Implications for construction management

Visual simulation has made its mark already upon the design process. In one case, a routine, similar to that used for N/C machine tools, was used to demonstrate how aircraft moved around runways and into hangers. From this it was possible to determine the most economic way of parking aircraft and positioning hangers. In another case, the movement of delivery vehicles across the site was superimposed to check for physical obstructions. A similar approach could be applied to the major activities associated with the construction of a building. This would permit outline designs to be scrutinised closely by construction managers/planners prior to more detailed design commencing. Improvements within design practice are likely only if those data attributable to the construction process are incorporated into design principles. The necessary construction data would include details of temporary works, plant and machinery, storage etc. and, although rarely associated with the final built form, are a significant proportion of the total cost of a project. However, there are some practical limitations which must be considered. For instance, it is unrealistic to expect the design to reflect every construction implication as some are unknown prior to work commencing on site. The handling of construction data, by a computer, is not inherently different from that of component data. Some of the features of a CAD system, namely overlay, clash and consistency checking etc. could be applied to these data once incorporated within the system. A prerequisite of this approach would be to formalise the construction planner's thinking in terms of the locations, sequencing and timing for all construction data.

2.2.15 General comments

The majority of users of all sizes and types used CAD systems for little more than automating drafting. Moreover, large organisations showed a strong tendency towards using CAD systems in a mechanistic way to replace existing manual methods of drawing production. However, some smaller organisations tended towards introducing multi-disciplinary working to concentrate upon design. For instance, exploring a greater number of design options, with each member of the design team being encouraged to contribute. It was clear that a CAD system user did not have to be large to be successful. A view held by many users was that willpower was the key to success, given that the correct choice of system had been made. It was also evident that a substantial data base management system was needed to succeed with anything beyond drafting.

3. INTEGRATED CAD SYSTEMS

3.1 Computer-aided design and evaluation

A system which is capable of expanding its function from drafting to the generation of information for construction estimating, planning and control purposes has been configured by the author and is shown in schematic form in Fig.4.

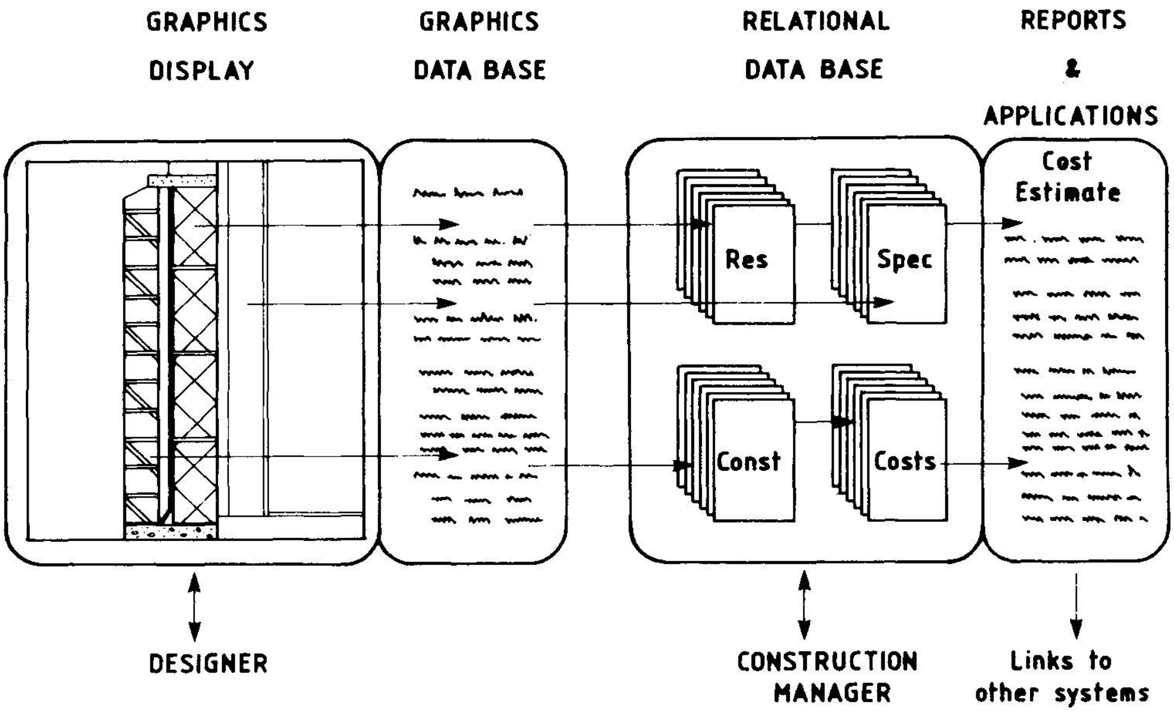

Fig.4 Schematic view of Computer-aided design and evaluation system

Currently, it incorporates the 2-D and 3-D (wire-frame) versions of AutoCAD linked to ORACLE, a relational data base management system and is supported on an IBM PC AT microcomputer with 640 Kb RAM. AutoCAD incorporates an attribute facility which enables each component, or assembly of components, to be identified in a library of geometric entities. This provides the necessary identifiers to the information-base of non-geometric data held in tabular form within ORACLE. Such tables include data on costs, resources, outputs etc. which are related to components via the identifier. A particular feature of the system is the use of a bar chart (Gantt) as an input medium. This has been created to secure the rapid input of time-related data and can be read by the system in the same way as any other geometric data. The various data can be incorporated in reports, of layout and content to suit the needs of individual users. Links to commercial construction project management systems are being explored. These are likely to be achieved by producing the necessary interface programs using the fourth generation programming language capability of ORACLE.

4. CONCLUSIONS

The findings of the research confirm the view that the industry appears to be content with automating traditional practices; that many CAD systems have the potential to integrate information for the management of construction projects; and that the data base management system is at the heart of the integrated system. Furthermore, the use of 3-D modelling systems is vital to exploiting CAD technology fully and to providing the mechanism for linking to systems for estimating, planning and controlling the construction process. However, the responsibility for incorporating the necessary data into the system cannot fall to the designer, when there is no obvious financial gain. In the absence of such consideration, the outcome is an increasing development of interest within construction management. As more organisations recognise the benefits of employing CAD systems, the overlap in the services which they offer to clients will continue to erode long standing professional barriers. This is likely to accelerate as technology and cost move within the reach of an increasing proportion of the construction industry. The computer technology necessary to help bring about improvement is available now, in one form or another, but requires willpower to force the benefits. The greatest possible waste of the technology would occur if it was used to automate traditional, manual methods without questioning their validity.

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