enables intelligent monitoring of civil engineering systems throughout the world from his office in Bristol, but also presents a profile highlighting potential failures, or problems, rather than just the raw data. This focusing of attention onto important issues saves the engineer time and improves decision making as a result.

Finally, my own work has involved the development of an intelligent multi-media system to aid technology transfer to busy building professionals. Studies on over sixty architects and building service engineers showed that when an information system is successfully matched to the building design decision makers preferred ways of learning it is likely to engender better communication and deeper learning. When information is not presented in a preferred mode people are likely to impose a preferred structure on that information. My research team have developed a number of unique information systems which tailor information to one of the four ways we believe engineers learn best. These systems, portraying information on energy conserving design, fire escape, quality and fire control, have now proved their worth in practice situations.

In short for IT to become truly effective in Construction it must become human centred and actually help decision makers make decisions. It must be integrated into their modes of operation as engineers. Information technologies must become informing technologies, supporting, rather than disabling, decision making.

Professor James Powell
Design Information Research Team
Brunel University
SERC's IT applications Co-ordinator for Construction

Editors' note: In a future issue of this journal full papers showing the range of such information systems, as developed on SERC's ITA Initiative, will be published to present more detailed information on this important area.

AN INTEGRATED SYSTEM TO AID THE PLANNING OF CONCRETE STRUCTURES: INTRODUCING THE SYSTEM

G Aouad and A D F Price[1]

ABSTRACT: This paper reports on the development at Loughborough University of a CAD-based integrated model to aid the planning of in-situ concrete structures. The system development started after a review of the planning models currently available and after a detailed questionnaire survey undertaken amongst the top UK and US contractors on the current status of planning techniques and information technology. The main aim of this system is to automate the planning process of in-situ concrete structures using data generated by CAD systems. So far, the integration of a CAD system (AutoCAD 10) and a computerized scheduling system (Artemis 2000) has been achieved on a typical IBM-PC. This enables the generation of network plans using AutoCAD which are then automatically transferred to the Artemis system for time and cost analyses. Traditionally, construction planners are faced with many conventional drawings and documents which are used to re-extract information relevant to their planning processes. Such an approach can be very inefficient as it involves data double-handling and is often error prone. In addition, current computerized construction planning applications are little more than the automation of manual formulations of plans. For example, data are fed into the planning system and computations are performed using either CPM (Critical Path Method) or PERT (Programme Evaluation and Review Technique). However, data relating to the planning process such as activity lists, resources requirements and durations are not automatically generated within the system. It would thus seem logical to devise a CAD-based integrated planning model which accepts data in its electronic format and involves some integration of the traditional planning approach. This paper introduces the proposed CAD-based integrated planning model and describes its different components. In addition, it discusses the system functional specifications and summarizes the main benefits and limitations of such a model.

Keywords: Planning, in-situ concrete structures, CAD.

INTRODUCTION

Results from a recent survey of construction practice revealed that 85% of UK and 67% of US contractors considered that construction planners extracted most information from conventinal drawings and documents to devise the master plan. (Aouad, and Price, 1991$_a$). Only 49% of Uk and 41% of US contractors thought that the extraction of information from drawings and documents could be considered as data double-handling. However, such an approach is highly inefficient and error prone as data extracted from these documents and drawings could be misinterpreted by construction planners. The proposed integrated system approach to construction planning could help to rectify problems encountered in the traditional working environment. The system is based on the concept of integrating low cost and powerful micro-based computer aided design and project management packages (i.e. AutoCAD and Artemis 2000) which are within the reach of most construction firms. The proposed integrated system should be more efficient, than traditional processes, and should provide a consistent flow of information whilst keeping data corruption to a minimum. In addition, data extraction is considerably reduced as information relevant to the planning process is initialised during the early stages of design.

PREVIOUS WORK

Several procedural and computer models have been developed as aid to the planning and management of construction projects. Procedural methods include bar charts, network techniques, line of balance, and heuristic rules. Most UK and US contractors regularly use bar chart and network techniques as their planning, scheduling and controlling tools (Aouad and Price, 1991). The most common computer models included those of expert systems, simulation techniques and CAD-based planning applications. However, only a few of these computer models are used extensively by the construction industry. The main disadvantages are the large amounts of data required; extra cost in terms of software and hardware; and the lack of flexibility needed by construction personnel to account for the unique nature of construction projects. A list of computer models previously developed as aid to the planning of construction projects is presented in Table 1.

Expert systems	Simulation models	CAD-based models
Constuction Planex	Siren	Retik et al
Platform	Produf	Atkin et al
MIRCI	Stochastic network model	Timberline software
FEPP	Construction project simulator	COMANDS
Time		Builder
Consas		Morad (CAD/CPM)
Ghost		OARPLAN

Table 1: Computer-based construction planning models

Hardware Requirements	Software Requirements
IBM PS/2 Model 70	DOS3.3
Colour Monitor	AutoCAD Release 10
30 MB Hard Disk	Artemis 2000 Version 2.30
4 MB RAM	Wordstar 3.3
80386 Processor	dBase IV
80387 Maths C0-processor	
A3 HP 7475 Six Pen Plotter	
IBM Dot Matrix Printer	
IBM Bus Mouse	

Table 2: Hardware and software requirements

Construction Planex is a prototypical knowledge intensive expert system for construction planning, and was developed, by Hendrickson et al (1987) in the US, to generate activity networks, cost estimates and schedules. It was designed to plan modular high rise buildings including excavation, foundations and structural construction. The different design elements are identified, the tasks or elements activities to install these design elements are then assigned. These tasks are then aggregated to form project activities. The Construction Planex model uses the CPM techniques to handle the scheduling task. The main limitation of the Construction Planex model is that it only accounts for relationships derived from physical relationships among building components. In addition to this interaction of trade and its effect on activity logic is not considered (Echverry et al, 1989: Zozaya-Gorostiza et al, 1989).

More recently, Builder was developed at MIT by Cherneff (1991), the Builder model generates construction schedules from drawings and incorporates two sorts of databases: one is used for drawing creation and manipulation; and the other for construction scheduling. Its key characteristic is the object oriented environment used to develop this system. This environment has facilitated the storage of physical objects such as doors, windows, walls, as well as generic tasks for their construction. The two knowledge bases of the Builder system are: Draw and Planner. Draw, a knowledge enhanced CAD system was used for drawing creation, recognition and manipulation. Planner, on the other hand, was adopted as a scheduling tool. Its knowledge of construction sequences, estimating data and procedures to produce the project network are combined to develop the construction plan. The main criticism of the Builder model has been that its crude bar chart output is not sufficient for site use. Raymond Levitt and his team at Stanford are currently developing the Object-Action- Resource planning system (OARPLAN). This is a knowledge-based system that generates a list of required activities and their precedence constraints for a construction project from a reasoned analysis of objects, actions and resources.

As part of its planning process, OARPLAN accesses design details either from a CADD system or database (Howard, 1991).

THE PROPOSED INTEGRATED PLANNING SYSTEM

The integrated planning system described in this paper is specifically aimed at assisting the planning of in-situ concrete elements found in multi-storey structures, and concentrates on concreting, steel-fixing and formwork activities The hierarchy of the work is illustrated in Fig 1. The integrated planning system can be used to model the various reinforced concrete elements such as beams, columns, foundations, slabs and walls. These elements are presented as symbols containing attributes relevant to the planning process such as construction method and dimensions. These elements are used to generate concreting, steel fixing and formwork activities based on work study data stored within the CAD model, however, this could be expanded to include other activities such as excavation work. The system automates the generation of network diagrams and thus eliminates the need for a manual representation of these activity networks. Such electronic representation of network also enables data transfer into project management packages for time and cost analyses.

The proposed system is unique in so much as it incorporates lisp functions that

synthesize reliable work study data and the generation of network plans has been fully automated within the CAD package. In addition to this, the system offers more facilities in terms of visualization and data processing, (Aouad *et al*,1993). These major facilities are described in the next section when discussing the functional specifications of the system.
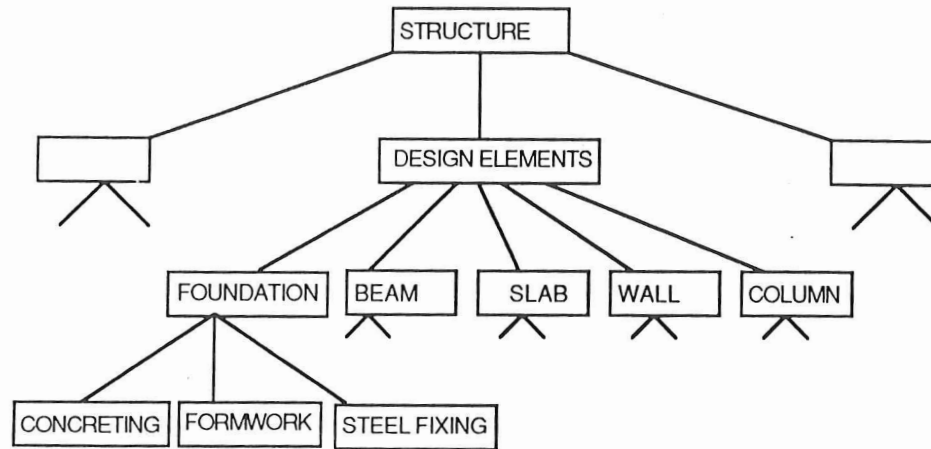

Figure 1: The hierarchy of work

Most of the existing systems have been designed to operate on powerful machines such as Workstations. The system discussed in this paper functions within the micro computer environment, the cost of which is well within the reach of most construction companies. In addition to this, the system integrates two packages which have already proven themselves to be popular with the construction industry. Also, the system automates the generation of construction plans (network diagrams) within the CAD system. A stronger link between the building model and the construction plan model is thus achieved. This allows changes to be controlled and monitored.

Jones *et al*(1988) identified a drawing database file as a set of records of alphanumeric description called drawing primitives. The ability to look at this drawing database is a major feature in assessing the suitability of a particular CAD program because data can only be extracted if an access to such database is provided within the system. AutoCAD supports such facility and further data manipulation can be achieved. Autolisp takes each AutoCAD drawing database record and formats it into an association list. This association list is not the actual autoCAD drawing database which is stored in binary format and proprietary (Autodesk Ltd. 1989$_a$ and 1989$_b$). However, the actual database is structured similarly to those file formats. Table 3 presents examples of the major AutoCAD drawing primitives coding found in association lists.

CODE	DESCRIPTION
0	Entity type
-1	Entity name (unique index)
1	Primary text value
2	Name: shape, block, tag
8	Layer name
10	Start of insertion point
11	End of insertion point
66	Entities follow flag (attributes)

Table 3: Sample of codes used within AutoCADD Association lists

An example of an association list is shown below and has been extracted from one of the program listing) to illustrate the structure of the drawing data stored within the AutoCAD drawing database.

```
(
(-1. <Entity name: 60000048>)        ; Unique ID number
(0. "INSERT")                        ; Entity type
(8. "0")                             ; Layer name
(66.1)                               ; Attributes follow flat
(2. "grec")                          ; Name of block
(----) (----)                        ; Additional lists
)
                                     -1. <Entity name: 60000060>)

(0. "ATTRIB")
(8. "0")
(10. co-ordinates)                   ; Insertion point for text
(40.400)                             ; Text height
(1. "5")                             ; Attribute value
(2. "LENGTH")                        ; Attribute tag
(----) (----)                        ; Additional lists
)
```

These association lists can be addressed by Autolisp routines. For instance, a symbol with specific attributes can be inserted into a drawing, the data can then be extracted from the database for further processing using an Autolisp program. Such a strategy has been adopted in order to develop the integrated construction planning application. In the above example, the geometrical attribute "LENGTH" can be extracted in order to establish quantities such as volumes, areas, etc.

FUNCTIONAL SPECIFICATIONS OF THE SYSTEM

The literature review and the questionnaire identified the need for a flexible and advanced CAD-based planning system (Aouad and Price, 1991a and 1991b). The system should be capable of integrating design (modelling) and management (planning, scheduling and control) information to help construction projects satisfy time, cost and quality constraints. Construction planners have traditionally produced network diagrams by hand then analyse them either manually or using planning packages. The system proposed imitates this traditional approach, but network diagrams are produced in an electronic format. In addition, the system offers more facilities in terms of visualising and processing data. The functional specifications of the proposed integrated system are summarised below:

* Modelling requirements
* Drafting requirements
* Quantities and materials scheduling requirements
* Time analysis requirements
* Cost analysis
* Reporting

The integration of a low cost but powerful CAD and project management packages could well help to satisfy these specifications as discussed below.

i) Modelling requirements

The system is required to model in-situ concrete components and their associated construction activities. The system should be user friendly and facilitate

* better visualization of the building model, site arrangements and equipment locations by incorporating 3D modelling facilities
* automatic switching between the different layers to keep various design elements, text and dimensions on different levels
* the storage of pre-drawn components (symbols), as well as components of variable nature, along with any textual attributes to be attached to these symbols
* the view of design elements from any direction or orientation
* the inclusion of the modelling requirements within the menu facilities.

ii) Drafting requirements

In order to produce drawings and details that are acceptable to industry, the system must satisfy certain drafting requirements that enable

* drawings to be produced from the 3D CAD building model
* different textual information be imported to drawings from other applications in order to enhance their quality
* drawings to be produced on screens, printers and plotters.

iii) Quantities and materials scheduling requirements

One of the main tasks of the proposed system is to generate quantities and schedules based on design information stored within the CAD model. To ensure that this is performed in an efficient manner, the system should

* enable the user to associate any set of design elements with network activities (quantities relating to these design element) automatically generated within the system. Areas, volumes, weights of reinforcement bars and activity durations are examples of such generated quantities;
* store data-related activities in different files for further processing;
* provide compatible data between the various required applications as further processing of quantities and schedules could be involved within these applications
* automatically update network diagrams when design elements have been modified
* incorporate a bills of material facility within the system

iv) Time analysis requirements

The main aim of the time analysis part of the integrated system is to determine total project duration. In order to achieve this, the system should be able to:

* process 'on the arrow' network diagrams
* perform CPM (Critical Path Method) calculations, including total and independent floats
* perform resource analyses and establish resources loadings and requirements
* support a customized version of the time analysis requirement
* automatically translate network diagrams into planning activities
* accommodate several scenarios, for example be flexible enough to permit different gang sizes and construction methods to be simulated.

v) Cost analysis requirements

In addition to time analysis, the proposed system should be able to analyse the costs of the project under consideration, therefore, the system should

* be capable of performing a cost analysis of the concreting, steel fixing and formwork activities associated with design elements
* produce costs based on the labour and material requirements
* allow for a close association between time and cost in order to establish an optimized working plan
* the cost analysis phase should be fully customised with a user friendly interface

vi) The reporting requirements

The reporting phase of the proposed integrated system is aimed at producing the reports, graphs and charts required to plan and control the construction of phase and should be capable of producing

* a detailed network diagram with all the descriptive information necessarily required by construction personnel. Colour coding should also be included on plotted and displayed charts and diagrams

* bar charts which are an important communications tool between management and site personnel
* diagrams such as histograms to illustrate resource levelling, loading and aggregation
* tabular reports incorporated within the system to illustrate activities status, costs and times

Once the various functional specifications of the system had been established the process of evaluating available systems could start. This involved a search for the most appropriate micro-based CAD and project management packages. AutoCAD 10 (CAD package) and Artemis 2000 (project management package) were chosen as they satisfied most of the criteria specified for the integrated system to be implemented. AutoCAD release 10 (Autodesk, 1989$_a$) was chosen to model concrete elements and their associated activities. This package satisfied most of the modelling, drafting and quantities and materials scheduling requirements of the integrated system. In addition, this micro-based computer aided design package has the following key features

* the package is user friendly and easy to use
* the system can be fully customized to the user requirements
* many data formats are supported by the software. CDF (comma delimited format), SDF (space delimited format), DXF (drawing exchange format), and IGES (Initial graphic exchange specifications) are examples of these data formats. This facility also allows drawings and files to be transferred to other systems and applications
* the incorporation of a programming language, Autolisp interpreter, (Autodesk, 1989$_b$), within the package enhances the quality of the product in the sense that it allows procedures to be associated with CAD objects
* the package has interfaces to external programs such as dBase and Lotus 123
* the package documentation and the vendor support are excellent
* the system is widely known and more than 400,000 copies were sold worldwide by the end of 1990. The questionnaire survey also revealed that 61% of US and 33.5% of UK contractors already use this package. The large number of AutoCAD users has encouraged the formation of user groups which are continually enhancing the product quality through the contributions of new ideas and suggestions

Artemis 2000 (Metier Management Systems, 1987) was chosen because of its capabilities in terms of power and facilities, even though the survey of contractors revealed that only 4% of UK and 5% of US contractors have adopted this system. The Artemis 2000 micro-based project management package satisfied most of the time analysis, cost analysis and reporting requirements of the integrated model. The major features of this package are

* the incorporation of a relational database within the system which is a key factor in developing micro-based integrated applications. Such an approach relies heavily on the concept of integrating CAD and relational database applications resulting from the lack of central databases which are usually only available on mainframes and minicomputers
* the incorporation of a high level command language within the package made its customisation easily achievable

* the network processing facilities provided within the package, which includes both 'on the arrow' and 'on the node' techniques. In addition, further facilities are provided for time, cost and resources management
* the interface with external programs which support the DIF (data interchange format) format, of which dBase and Lotus 123 are examples. This facility was used extensively during the development of the integrated system, particularly during the data transfer phase
* the good documentation and vendor support

The development of integrated systems can only take place if data can be freely passed between the various applications. There is a lack of compatibility between AutoCAD and Artemis 2000 in terms of data formats, and standard formats for data exchanges do not currently exist. However, the availability of computer programs such as dBase IV (Ashton-Tate, 1988), which can support a large number of data formats can be utilized as a temporary solution. The proposed integrated system uses, dBase IV as a repository system of the comma and space delimited format (CDF and SDF) data generated within AutoCAD. These data have to be translated by the dBase package into DIF (data interchange format) files for further use by the Artemis package. The next section considers this aspect when discussing the different stages of the integrated system.

THE THREE STAGES OF THE INTEGRATED SYSTEM

A simplified layout of the proposed integrated planning system is presented in Fig 2. and comprises three sub-systems, namely: modelling, data transfer, and planning. These sub-systems are now described in detail.
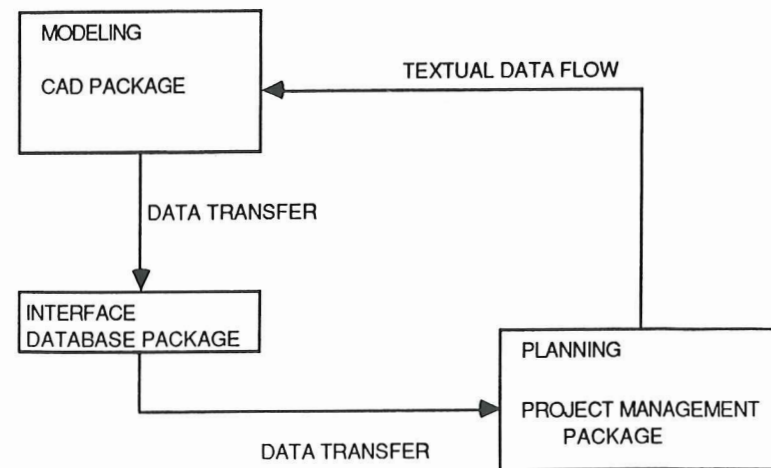

Figure 2: Simplified layout of the integrated model

Modelling sub-system

The modelling sub-system is implemented within the AutoCAD environment. The main task of this sub-system is to model the concrete elements, formwork components, and reinforcement bars associated with in-situ concrete structures in the order that they will be built on site. These design elements are created as blocks or symbols which can be inserted at specific locations. Geometrical attributes and other properties relevant to the planning phase can be attached to these elements; the construction planner can then select any set of design elements and associate them with construction activities. These activities can be placed in the CAD-based network diagram model for later use. Attributes of any value can be attached to the design elements and new elements introduced by creating new symbols to represent them. Autolisp procedures have been associated with AutoCAD objects to enable quantities (such as areas and volumes of concrete, weights of reinforcement bars, and durations of activities) to be produced automatically within the system. The durations of activities are based on two sorts of databases: a work study database developed at Loughborough University (Price and Harris, 1984_a, 1984_b, 1984_c) and a company database established from the Wessex and Spons building price books (Wessex, 1985; Davis *et al*, 1988). In addition, the system is flexible enough to allow construction planners to use their own experience and historical records rather than these databases. The questionnaire survey revealed that most UK and US contractors based their estimates of output rates on experience and historical records. In order to provide planners with more reliable figures, it was decided to incorporate these two sources of output data.

Data transfer sub-system

The work study data base is applied through the application of several Lisp functions. If the user is not satisfied with these functions, the database approach should be adopted or the functions modified. As the lisp functions have been produced in a modular format this modification should be relatively simple.

The data transfer sub-system passes data extracted from the CAD-based design and network diagram models through the repository system (dBase IV) into the planning package for further processing. This sub-system has been implemented within the dBase IV environment. The different stages of this sub-system are summarized in Fig 3.
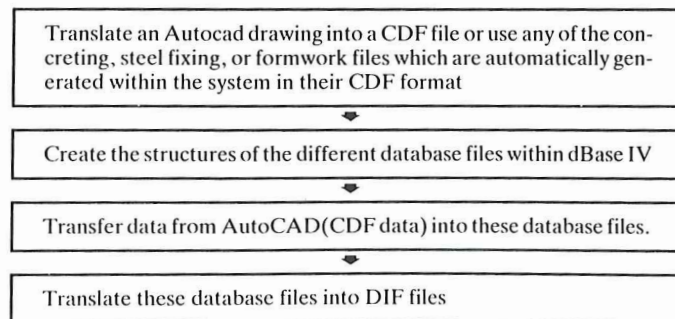
Translate an Autocad drawing into a CDF file or use any of the concreting, steel fixing, or formwork files which are automatically generated within the system in their CDF format

⬇

Create the structures of the different database files within dBase IV

⬇

Transfer data from AutoCAD(CDF data) into these database files.

⬇

Translate these database files into DIF files

Figure 3: The different stages of the data transfer sub-system

Planning sub-system

The final part of the integrated model is the planning sub-system which is implemented within the Artemis planning package. The main tasks of this sub-system are to: analyse the network transferred from the CAD model in order to establish the total project duration and cost; produce the required charts such as bar charts and histograms; and perform the resource management task through techniques such as resources levelling and aggregation.

THE SYSTEM REQUIREMENTS

Integrated computer applications involves the coupling of many software packages, the requirements in terms of power, memory and financial aspects should not be underestimated (Aouad and Price, 1991_c). The proposed integrated system runs on an IBM microcomputer and the combination of the following hardware and software requirements had to be satisfied in order to run the program efficiently.

The questionnaire survey revealed that most contractors were already using micro-based CAD and project management packages under the Disk Operating System (DOS). In addition, many of these packages were installed on the same computer. These findings give some encouragement as to the possibility of the integrated planning systems being implemented on a single micro-based machine. Construction planners should, therefore, seriously consider the re-appraisal of current practices due to recent technological advances and decreased costs of software and hardware. This is also backed by the view that a CAD-based integrated planning application can offer substantial benefits when compared to the traditional approach.

BENEFITS OF THE PROPOSED INTEGRATED SYSTEM

The main benefits that the proposed CAD-based integrated system offers to construction planners, in particular to the planning of in-situ concrete structures, are as follows

* a substantial flexibility available when selecting any set of design elements associating them with construction activities such as concreting, steel fixing and formwork erection

* visualisation of the building model in order to account for site restrictions and equipment and trade interactions. This facility is of particular importance when selecting pouring methods and when detecting reinforcement clashes

* components or design elements can be placed on the screen in the order they will be built on site

* project management information can have its origin in the electronic design model. For example, the network diagram model is produced within the CAD package and automatically transferred to the planning package for time and cost analyses

* quantities are automatically generated within the system for any set of design elements, thus reducing taking off mistakes

* drawings could be sent to other departments for further processing as in the manufacturing industry

* activity durations can be calculated using either a work study database or a company database, in addition to the use of experience and historical records

* activity durations are automatically updated when design elements are modified

* the repetitive and tedious task of producing (and revising) the network diagram is fully automated and computerized within the CAD system

* the modelling, data transfer and planning sub-systems are fully customized to provide a user friendly system

* the system can be used to evaluate the network diagrams. The flexibility exists to determine how the sequence of activities, gang sizes and the elements within selection sets influence project duration and cost. An optimized network can thus be produced

LIMITATIONS OF THE PROPOSED INTEGRATED SYSTEM

The main limitations of the system are at this point the system is relatively slow and highly experimental, future development should help to improve some of the existing limitations that are listed below

* the system currently does not interface with any expert system program

* the user has to identify elements of work and the logic behind the construction plan

* the building product model is not defined within the system

* the system can only analyse concreting, steel fixing and formwork activities associated with in-situ concrete elements

* the system is restricted to 'on the arrow' network diagrams

A BRIEF DESCRIPTION OF HOW THE SYSTEM WORKS

The integrated planning system comprises of three different sub-systems, namely: modelling, data transfer and planning. In the modelling phase, reinforced concrete elements are modelled, placed and assembled in the AutoCAD package. The user can then interact with the assembled building model using the various pull down menus specifically designed to facilitate such tasks. The planner can highlight any set of design elements using a 'mouse' and then place activities associated with these elements, such as concreting, steel fixing and formwork, in the AutoCAD-based network diagram model. The activity durations are based on actual design quantities generated within the model.

In the second sub-system (data transfer), the AutoCAD-based network plan model is transferred to the Artemis 2000 package via dBase IV for time and cost analyses. A facility has been provided within dBase IV to automate this task.

In the final sub-system (planning), the user can interact with the customized planning model to perform the time and cost analyses associated with the network diagram

transferred during the second phase. The system allows precedence relationships and resource constraints to be entered manually in order that the planner can experiment and consider various alternatives. Pop-up menus and help facilities are provided at all levels to facilitate such tasks. The CPM (Critical Path Method), cost and resource management calculations are all undertaken during this phase.

As the developed system is not linked to an expert system, the user (construction planner) selects from the building model elements to be analysed. The system automates the generation of the construction activities associated with the selected design elements (durations of activities are calculated by the system). The logic of sequencing construction activities is not defined and thus the user can decide on such sequencing of activities. The user role in each of the main three components is as follows

1. At the modelling stage, the user can select elements from a predefined library of symbols . He/she then selects any set of design elements which needs to be associated with a construction activity. The system calculates the activity durations, but the user decides on the order or logic of these activities.

2. At the data transfer stage, the user can interact with the system in order to transfer information from AutoCAD to Artemis IV. The phase is fully automated, and the user role is very minimal.

3. At the planning stage, the user can run the time and cost systems.

CONCLUSIONS

A CAD-based integrated system designed to aid the planning of concrete structures has been introduced. The potential of micro-based computer aided design systems as an aid to improving the management and planning of construction projects has been discussed. The benefits that these micro CAD-based integrated systems can offer over traditional approaches have also been highlighted. In a traditional approach most data used by managers and planners originate from conventional documents and drawings which are revised on a regular basis. Any changes, if not recorded, will lead to a disturbance of resources, materials and scheduled activities. The integrated planning system has been suggested to rectify problems found in the traditional approach. In such a system, data are handled in its electronic format, thus reducing data double handling and improved management of information is achieved through a better system of communications. It is concluded that the application of such systems could soon become a reality as most contractors have started to appreciate the benefits CAD systems can offer to the management and planning of their construction projects. This paper briefly describes a proposed integrated system and highlights its major components and the benefits which could be gained from the further development of this system.

REFERENCES

Aouad, G., Price, A.D.F., 1991$_a$, Questionnaire survey on current practices of planning and IT amongst the top UK and US contractors, internal *report*, Dept of Civ Engrg, Loughborough Univ of Tech.