CAD in process plant engineering

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Developing CAD systems for the design and layout of process plant involves an investment of millions of pounds. Today the proven benefit of using such systems is apparent, but without commitment and foresight from software developers such tools may never be seen in the market. One such product, PDMS, was a joint development between CADCentre, Isopipe and Akzo Engineering, started in 1974 and first sold in 1977. Since then many thousands of man-hours have gone into developing the system.

Introduction

Computers have been used in process plant engineering for more than 20 years, and it is difficult to imagine engineering now without computing, even in the limited and rather fragmented forms that have so far gained general commercial acceptance. The usage of computers is accelerating in scale and in scope; acronyms such as CAD (computer-aided design), CAM (computer-aided manufacturing) and CAE (computer-aided engineering) have appeared, and commercial vendors are offering to solve almost any problem known to designers or managers. Computer aids to engineering offer great benefits, but the dynamic state of the techniques and the cost of faulty choices, either in computing systems or applications, inhibit engineers from reaping today's benefits or from planning the future of their art.

'Design' never exists in abstract or in isolation. It exists only as part of a properly managed process intended to transform an identified need into a working engineering means of satisfying that need — in our case, a plant. As such, 'design' must embrace not only the creative, analytical process classically (but confusingly) called design; it must also cover the drafting operation and the use of associated data generated from drafting which enables management to mobilise and control the resources needed to build the plant.

Since 'design' in this definition is such an integral part of the engineering profession, we must set out clearly the aims that we wish to attain in the design process by using computer-aided design. Appropriate aims for CAD are therefore suggested as:

- extending the designer's capabilities to perform calculations, assemble, manipulate, retrieve and present data about the design, and visualise and communicate the design
- not only enlarging the scale of the designer's capabilities but also increasing the reliability of calculation, data, drawings and communication
- reducing the time spent by designers, draftsmen and detailers in the whole design process.

The plant engineering process

Process plant design is more than the task of performing calculations and making drawings. The complexity of a process plant, the large number of people simultaneously engaged on its design and the wide range of engineering disciplines and functions represented by those people require an orderly environment in which corporate control, project control, competent design, inter-discipline co-ordination and plant construction can be carried out.

Corporate management must set performance standards, arbitrate between conflicting demands of different disciplines and promote good communications between designers, managers, suppliers and clients.

Designers must apply their specialist engineering discipline to the problems in hand, co-ordinate their own efforts within the project team, and provide the final drawings and specifications for plant construction.

There is, therefore, no single 'design problem' amenable to settlement by a single 'design solution'. There is, instead, a set of identifiable design tasks which must proceed in an orderly sequence through a defined management structure from specification to construction. The progression is illustrated by Fig. 1, and three main consecutive phases of the project from conception to completion are characterised by the principal (but not exclusive) concern of the phase: namely, design, drafting and management. In practice, the phases often overlap in timing and do not have rigid boundaries, but Fig. 1 highlights the gradual shift of emphasis from specifying the plant, through design and drafting to its final manufacture and construction in accordance with the specification.

The design phase

The design phase is examined in more detail in Fig. 2. Starting with a project specification which states what is to be achieved, a single designer or small group of designers apply their own experience and creativity to establish an overall design concept that defines how the specification will be met. Development of this concept is constrained by the level of engineering science and physical property data available to the group. In process plant terms, this procedure would start with a production requirement, which would be translated into a flowsheet by chemical engineers using chemical data, physical chemistry and chemical engineering science.

The overall design concept expressed in

the flowsheet is then available for specialist engineering disciplines (such as equipment, piping, electrical or instrumentation) to produce more detailed design information on the components of the plant called for by the flowsheet through the application of their own skills, physical data and engineering sciences. During this stage, for example, a distillation column specified on the flowsheet by its diameter and height would be worked up into an outline engineering drawing by an equipment designer, combining considerations of structural analysis, stress analysis, metal properties and fabrication techniques into an outline engineering design of the column.

An important element at the specialist engineering stage of the design process is the creation of a three-dimensional conceptual model which establishes how all the components of the design concept are to be arranged so that they fit within the space available and fulfil the project specification. The conceptual model must be set up also in accordance with relationships existing in the design concept: for example, equipment must be connected by pipes in strict conformity with process flow; equipment elevations must be correct etc. Relationships are an important part of the conceptual model, even though they may be implied or stated in words rather than being obvious physical attributes such as diameter, flow rate or direction.

The principal characteristic of the design is the problem solving approach, by which specific design features (for example heat exchanger designs) are subjected to logical, well established and often extremely complex mathematical procedures. Normally, in these procedures a small number of design parameters undergo large-scale analytical and numerical manipulation to yield a relatively small amount of data defining a design answer.

The obvious difficulties of solving the problem tend to obscure a considerable amount of manual design work devoted to finding and checking design parameters and to communicating information through the team of specialist designers.

The drafting phase

One main communication task is that of providing a single, visible manifestation of the conceptual model to all staff to ensure that all design work is carried out on a correct, up-to-date, management-authorised design basis. Since engineers communicate most easily through pictures, drawings are accepted as the best means of communicating and co-ordinating information flow within and between all phases of the project. Two principal drawings of paramount importance for these purposes in process plant design are the co-ordinated layout drawing and the piping and instrumentation diagram (or P&ID). The co-ordinated layout drawing controls and records the arrangement of the plant components in the available space, and the P&ID expands the information of the relationships contained in the flowsheet.

Production of these (and most other) drawings is centred in the drafting phase of Fig. 1, when the overall design concept is released for detailed engineering to be performed by specialist engineering disciplines such as civil, equipment, piping, instrumentation and electrical engineering groups. Each of these specialist disciplines has a design task of applying its own engineering science to an aspect of the overall design concept to produce detailed specifications of the components (steelwork, vessels, pipes, valves, motors, control valves etc.) making up the conceptual model. An integral and major method of validating and communicating these detailed specifications is the engineering drawing, produced by each specialist discipline to its own format by the drafting process (Figs. 3*a* and *b*), employing drafting conventions to convey information in a stylised common format.

Because drafting is such a large and intgral part of the detailed design engineering process, drafting and design are often treated as a single operation. They are, however, quite separate, as Fig. 3 shows. An essential preliminary to drafting is the detailed specialist design work that establishes the physical characteristics (type, shape, dimensions etc.) of the components which will fulfil the design concept.

These components and their characteristics will vary for each specialist discipline, and they are represented on drawings by symbols and techniques appropriate to that discipline. The drafting techniques used to present the components on all drawings, however, are totally formalised in their use of projection, scale, symbolic representation and dimensioning and in standards adopted for annotation, drawing sheets etc. across all disciplines.

To illustrate the process, consider Fig. 3*a*, where the overall design concept in the form of the flowsheet is taken up by the layout designer. His first task is to obtain outline sizes and shapes of the process equipment (the 'components') and consider how they should be arranged to satisfy the process by applying the specialist disciplines of layout design. The result of this operation is a layout that exists in the designer's mind and which must be transferred to paper so that other engineers can visualise and understand the layout.

Accordingly, very simple representations of the equipment are conceived to distinguish between equipment types. These representations are then drawn to scale, usually in plan using the drafting conventions, and the resulting specialist engineering drawing is the equipment layout, understandable by any other engineer. Addition of material obtained from drawings produced in other disciplines (representing their aspect of the design concept) converts the equipment layout into the co-ordinated layout drawing, used as the master plan for allocating space in the plant among the conflicting demands of the various disciplines.

A similar, but somewhat simpler, procedure can be seen in Fig. 3*b* for the electrical engineering discipline. The overall design concept is still the start point, but the part of the model under electrical engineering consideration is, say, the power distribution required to serve the equipment shown on the flowsheet. Again, a necessary detail design stage is required to establish the 'components' needed for power supplies (motors, switchgear, cabling etc.), but in this case the relationships between the components must be considered to establish cabling connectivity. Once these components and relationships have been established, however, and the electrical drafting conventions are defined, the common drafting process is applied to produce a totally different form of drawing — a power distribution diagram. Later drafting work will use this diagram as a basis for detailed drafting and scheduling for manufacture.

The important feature of Figs. 3*a* and *b* is the commonality of the actual drafting work, which, when applied to different engineering disciplines, produces many different forms of drawing. The commonality of drafting and the large amount of drafting work in a project have attracted much management attention in the past to improve company performance in the whole drafting phase.

The management phase

Production of the detailed engineering drawings initiates a change of focus from the tasks of drafting to those of managing the manufacture and construction stages, and management becomes the major priority in the project. Manufacture and construction must be based on the engineering data contained in the specialist engineering drawings, combined with the cost and schedule parameters set by project budgets and completion requirements. Fig. 4 illustrates some of the essential steps of this, the 'management phase', and shows a further necessary consideration in the injection of company management document formats so that design and project data can be presented in a recognisable authorised form, enabling staff to proceed with procurement, manufacture etc. Although the management phase may appear to many creative engineers and designers to be less interesting than the preceding design and drafting phases, the

challenges of management are no less demanding on the ability and creativity of engineers.

Evolution of CAD use

The three project execution phases discussed above impose diverse and apparently conflicting requirements on an integrated plant design and management system. An obvious difference appears in the 'problem solving' and 'data handling' aspects.

'Problem solving' is often based on a few imput parameters which are fed into a complex mathematical algorithm, from which an answer emerges as a small amount of data. In cases where an overall solution is required for a set of interdependent problems in a sequence or in a loop, the data volume in terms of both input parameters and the answer is relatively small, even if intermediate data transfer between design stages requires designer intervention to accept or modify parameters. Single- or multi-column distillation processes represent one typical design task employing complex mathematical computing routines based on small data volumes.

'Data handling' requires the input, processing and distribution of large volumes of data, with little or no mathematical processing. The data usually consists of single simple facts established by the project team, and covers diverse topics such as process temperatures and pressures, pipe sizes, piping component quantities, drawing numbers and costs. Processing is usually in the form of extremely simple addition, sorting or merging of individual items of data. The problems of data handling arise mainly from the volume of data and the many different types, plus the consequent effects that changing one data item can have on many other data items.

Historically, computer use in the industry has attacked these two well defined types of situation separately, partly because of the directly measureable benefits that were obtainable and partly because computing equipment and techniques of scientific computing and data processing, developed for general use outside the industry, could be most easily adapted.

In the 'problem solving' area, programs for complex calculations in fields such as:

- distillation (CONCEPT, MULTICOL, SS19)
- heat transfer (HTFS)
- mass transfer
- reactor design
- structural analysis (STRUDL, NASTRAN)
- pipe stress (PSA5, PIPESTRESS, TRIFLEX)

became available from the early 1960s onward, and are now so powerful and economical that their use is virtually essential for efficient design. Benefits gained by the use of these programs include the following:

- Designers produce more design results in less time.
- Designs are completed in shorter elapsed times.
- More alternative designs can be explored before one particular solution is adopted.
- Designs are more accurate, with less chance of arithmetical error.
- Design methods can be standardised within the company.
- Design answers are more reliable.

Over the same period, the 'data handling' area employed conventional commercial data processing procedures of mass data handling, file manipulation and printed output reports. Most of the work was (and is still, largely) concerned with bulk management information for functions such as:

- project costing
- CPM/PERT scheduling
- materials management (for example COMPAID, CAPICS, ISOPEDAC).

Where this type of program requires an interface with design or drafting (for example to enter piping information from

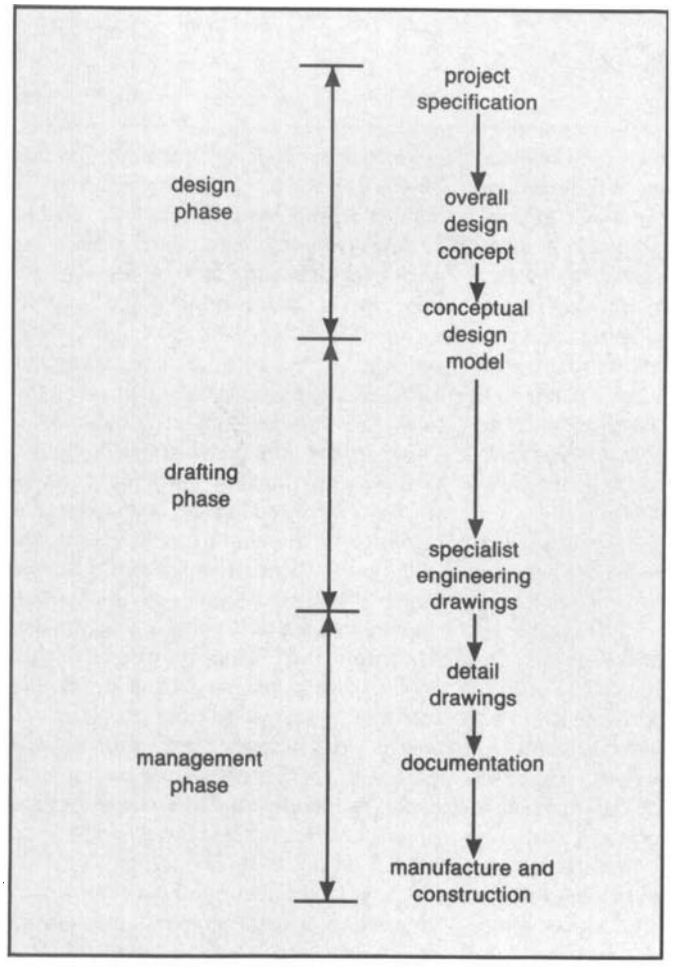

Fig. 1 The plant engineering process

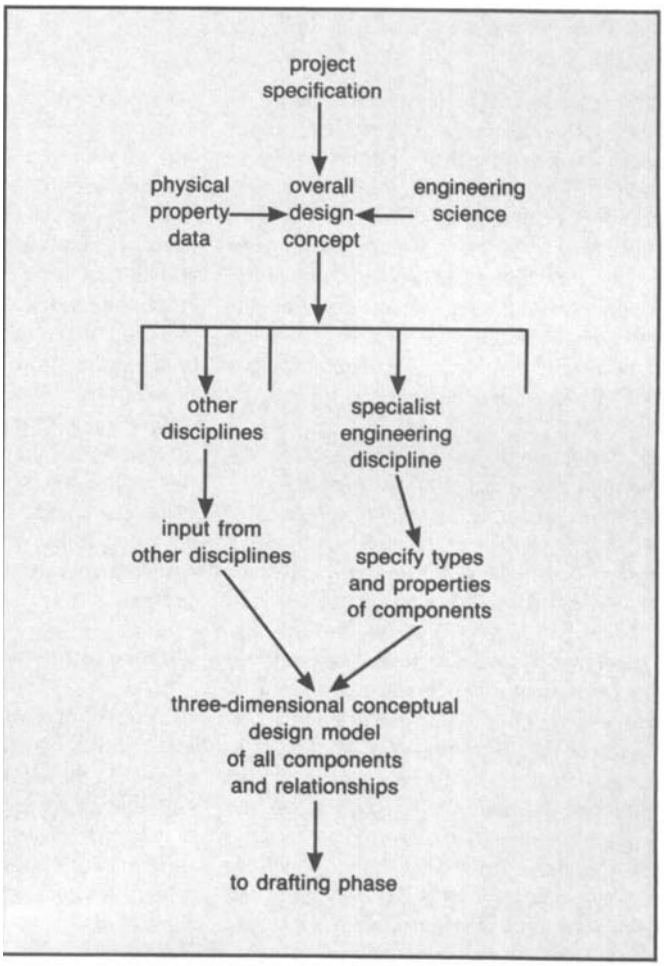

Fig. 2 Project development — the design phase

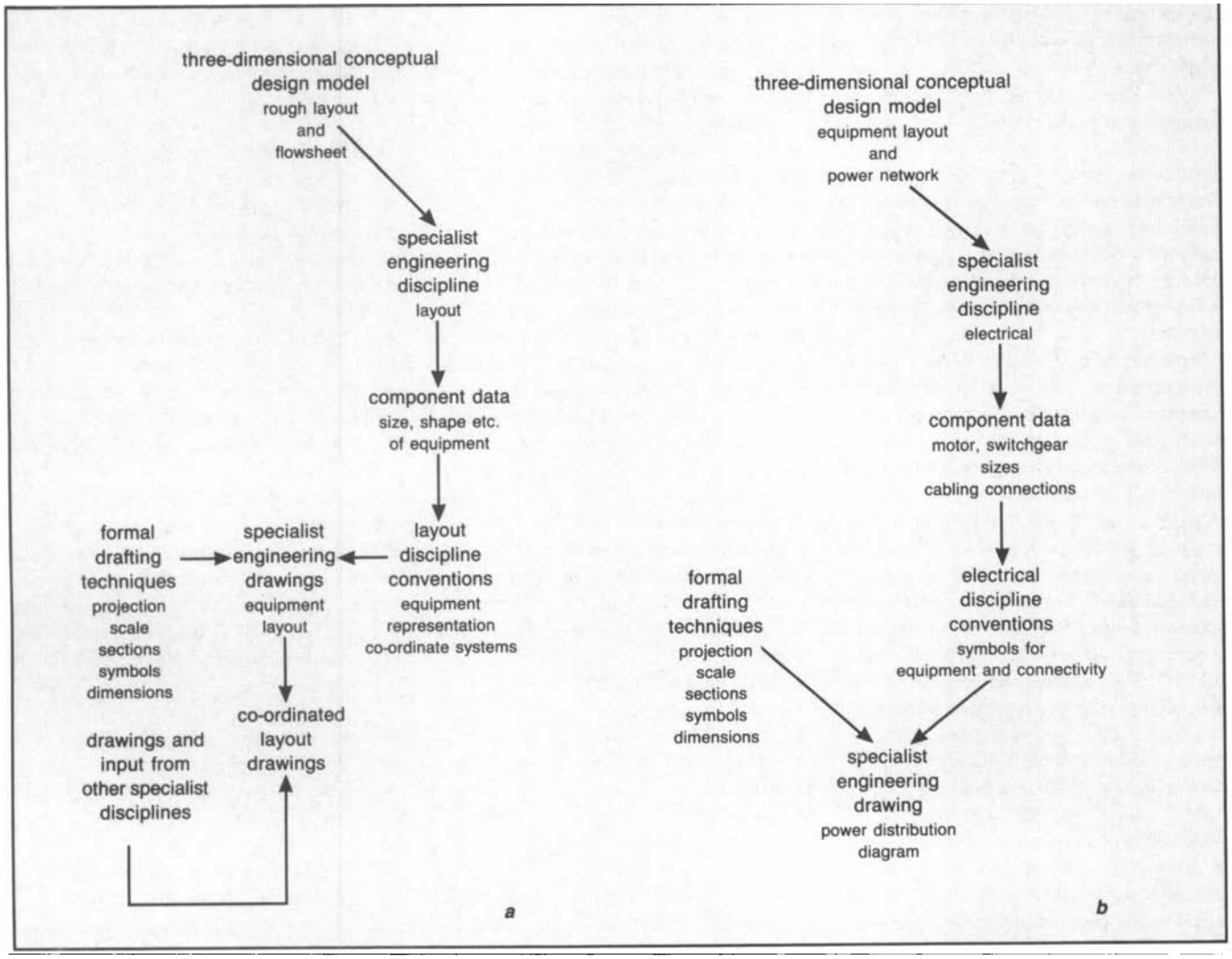

Fig. 3 Drafting phase
a Layout *b* Electrical

a layout drawing), a highly structured data entry system is necessary. Similarly, output reports for use by designers or managers tend to be rigid in format, terminology and content because of the limitations of data processing techniques. These disadvantages have not prevented widespread use of the programs because the management benefits gained have justified the imposition of extra data disciplines on designers. Principal benefits identified include the following:

- reduction in detail drafting and clerical hours spent in counting, listing etc.
- more accurate and reliable reports
- better project management based on better and faster information on, for example, material or cost changes.

Both types of program were originally run on large mainframe computers as batch processes. Input data was converted to punch cards or tapes for entry to the computer, and answers were output almost entirely as printed lists. Some programs had a graphic facility for making a drawing from the input data, but only drawings whose style, symbology and format could be predetermined were possible. COMPAID and ISOPEDAC are programs for producing stylised drawings of this nature (piping isometrics).

Developments in mainframe computers and computing languages which allowed multiple-user time sharing encouraged the development of conversational programs having facilities for questioning, prompting and helping the user to enter and check data fed to the program. A later development of this type of program also permits the user to see and act on the data created by the program from the user's input parameters during the running of the program. This 'interactive' facility means that the designer can ensure that the program processes only valid parameters and stores only valid accepted data, which can be refined or changed in a future interaction with the program.

Historical developments

Advances in computer hardware led in the late 1960s to the 'minicomputer', a physically small but powerful machine, capable of operating in normal office conditions and available at low cost. The performance/cost characteristics of minicomputers permitted them to be dedicated to specific functions whose immediate cost benefits covered the relatively low cost of the machine. New methods in computer graphics, when programmed for dedicated minicomputers, produced the now familiar drafting systems. These systems, combining human interaction and computer graphics, enable a draftsman to create and modify an engineering drawing very rapidly.

Drawings are produced by system commands which set up lines, curves, symbols, letters etc. in the computer memory. The draftsman can see the drawing as he develops it by means of a visual display unit, on which the computer displays the drawing currently held in memory. Repeated interaction between the system and the draftsman develops the initial blank sheet into a finished drawing, which can then be computer-plotted on normal drawing office media. High-quality drafting and appreciable drafting productivity gains can be made, but the draftsman must start from a designer's sketch or instruction, and must have a knowledge of his engineering discipline to make good drawings. Hence these systems only affect the drafting phase, and have no impact on design.

A later (and still current) development in computing systems concerns the way in which data is stored and handled within a computer as a database. Before the

development of database techniques, each program held its own data separately in a format suited only to the needs of that program. Consequently, one data item to be used by several design programs had to be entered separately to each program, possibly in different formats. Also, data in the format used or output by one program could not easily be used by another program, and manual inter-program transcription was required.

In a database, however, each data item is stored only once in a generalised computer format. Data items can be entered to a database in designer-specific terms and formatted by the computer; more significantly, the formatted data items can be accessed by any suitable design or data management program.

Since a data item is generally available, it need be entered only once by the engineering discipline responsible for its generation, but it can be accessed and used by any other discipline, which may generate from it dependent data items that are also stored in the database. When the basic data item is changed by its designer in response to a project change, the dependent data items can be located and changed correspondingly by the database operating system. Access to single data items or groups of items can be made quickly, easily and in designer terms; thus project or design changes can be made relatively easily, and their consequent effects highlighted for design action.

All these developments — minicomputers, workstations, databases and graphics — have already been employed commercially to provide new forms of CAD systems that suggest a pattern for developments of future installations which will integrate design, manufacture and management.

Integrated plant engineering systems

Improvements in process plant engineering will be greatest when the three phases of design/drafting/management are based on a common store of data, starting at the design concept and expanding through detail design to final construction. Under these conditions, all design and management action can be based on accurate information; thus performance and productivity improvements can be expected. Application of some current and possible future concepts to the problem solving, drafting and data handling requirements of the engineering process discussed enables the following aims to be suggested for an integrated engineering system:

- Integrate the design/drafting/management process through a common store of data defining all aspects of the project, and a common management procedure defining all inter-stage communications.
- Create a computer model of the overall design concept, and progressively update it to the final detailed three-dimensional design model of all components, their properties and their relationships.
- Transfer all necessary data from the model to the common data store.
- Produce pictures or drawings of the model or any group of components in the model.
- Develop problem solving programs to receive input parameters from the common data store and to return output answers to the store for incorporation into the model.
- Employ database technology to manipulate all the data in the store.
- Employ the computer model to drive computer-aided techniques for plant component manufacture and construction.

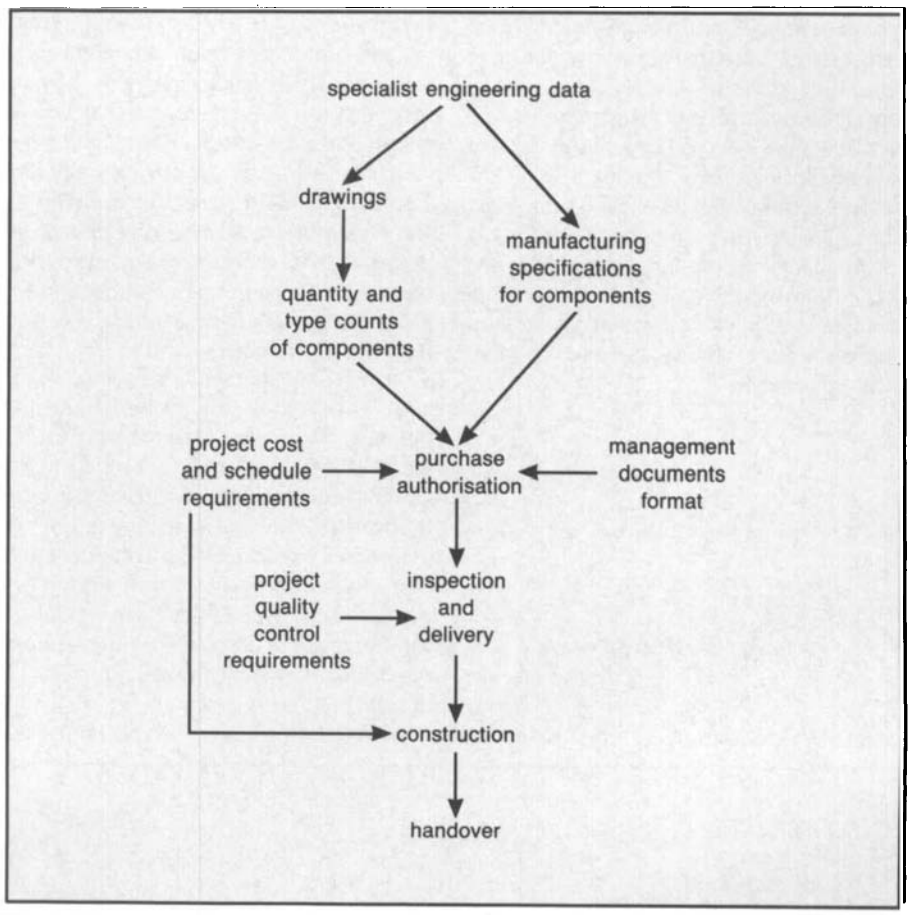

Fig. 4 Management phase

The sum of all these aims is the total computer-based integration of the entire management of a plant project from conception, through design, manufacture, construction and operation to final obsolescence — which may represent a 15-year time span. Although this goal is beyond our reach today, enough proven commercial work has been done to indicate that it is realistic. To illustrate the current state of the art, two systems in commercial use can be examined briefly and their features compared against the aims set out above.

Current commercial design systems

The systems considered, PEGS (Project Engineering Graphics System) and PDMS (Plant Design Management System), operate in different parts of a project for different purposes at different times, but both share some important common system design features:

- a database holding all system data
- a partial model of the design, held in the database
- operating programs which access system data for performance of design, or information processing tasks
- graphics capabilities for presentation of database information on drawings
- interactive operation using designers' terms and language
- operation on minicomputers and graphics workstations
- ability to transmit or receive data to or from other computer systems.

Both systems therefore fulfil in part some of the aims defined above for the total integrated system.

PEGS

PEGS is concerned mainly with managing the 'process data' — that large amount of data items needed to define the properties of plant components, process conditions and piping, together with the relationships between components and their shared properties. The properties of a component considered in PEGS are factual data items which are specific to that component. For example, a pipe has the properties of identity number, specification, terminal

points, nominal size, material, process fluid, temperature range, pressure range, flow rate etc. The properties are not unique; one specification applies to many pipes, or one process fluid may flow between several vessels through several pipes.

Relationships may be either hierarchical, through which one component 'owns' other components on a designer-specified basis, or relationships may arise through components having certain properties in common. For example, a pipe is a member of the hierarchy:

process unit
|
owning systems
|
owning pipes
|
owning piping components
etc.

and these relationships can be held in the database. A pipe also may have relationships arising from properties which are common to other pipes (for example specification, connection to a vessel, nominal size, process fluid etc.), and pipes which are related by any of these properties can be identified in the database (Fig. 5). The relationships shown do not include all potential relationships between a pipe and other parts of the project; of those shown, PEGS handles many of greatest interest to the process engineer.

Understanding relationships is made easier when they can be visualised; the piping and instrument diagram serves this visualisation need in plant and piping design. PEGS is able to use the hierarchical relationships in the database to assist draftsmen to produce these vital drawings correctly and quickly. In this, the system employs conventional interactive graphics techniques and information transfer from the database driven by instructions from a draftsman.

While the P&ID is a major project document, it must be supported by reports listing groups of project components of interest to designers and managers, normally on the basis of common properties. Examples of reports familiar to designers and managers include the equipment list, pipe schedule, valve schedule, list of users of one particular utility, instrument schedule etc. These and any other required report can be produced from the PEGS database.

Experience of the system indicates benefits in the following areas (Ref. 1):

- data input — simplified, since each data item need only be entered once to be available thereafter to all users
- data consistency — improved, since the same data item often appears on many documents and is always identical on each one
- design consistency — checks can be made to prevent some errors; for example, no item numbers can be duplicated, and two single-phase process streams from a

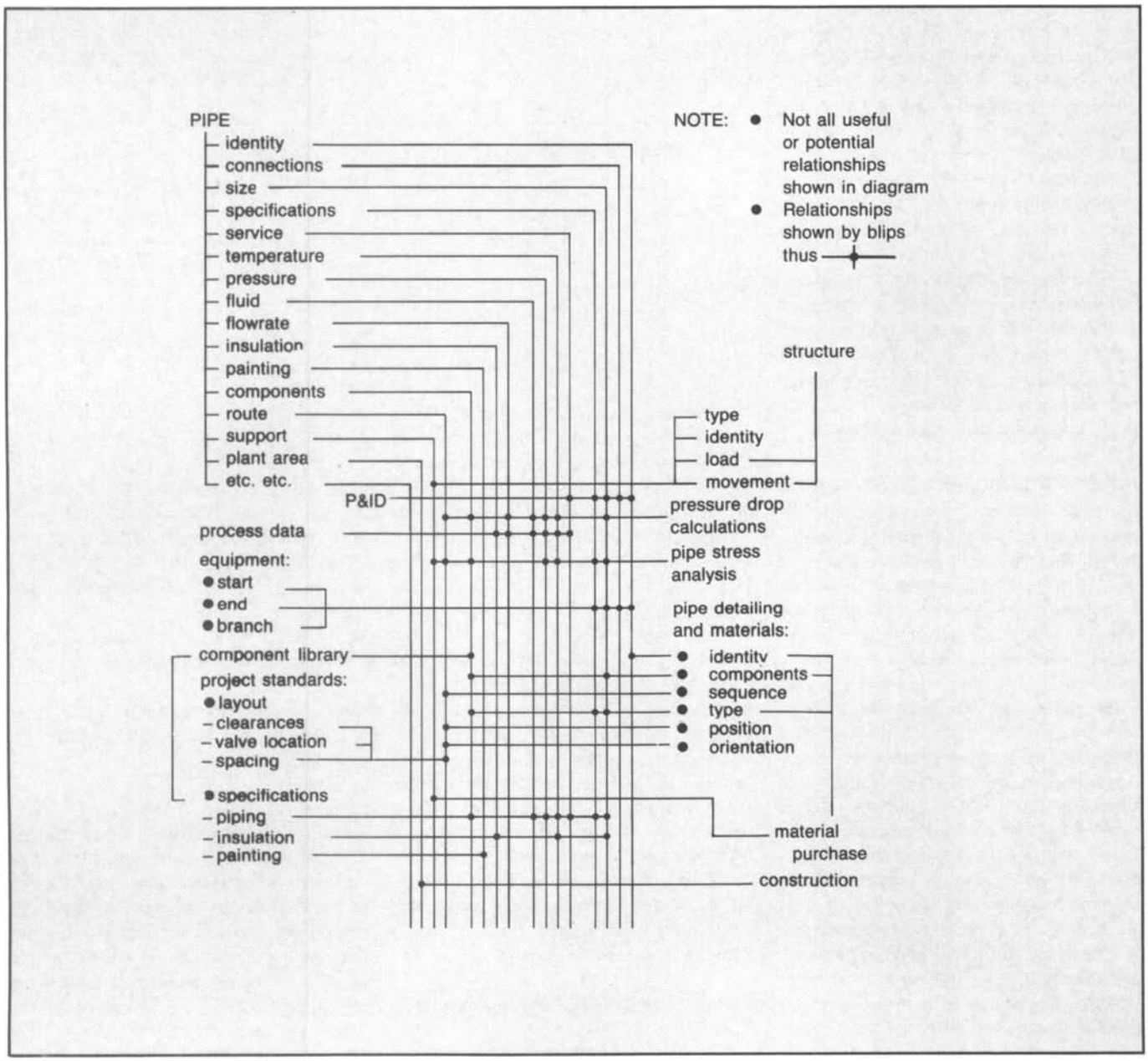

Fig. 5 Relationships, using a pipe as an example

common source must have identical composition and properties

- P&ID production — improved accuracy
- change management — simplified,

because once a data item is changed its impact on other parts of the design can be highlighted for action.

PEGS can thus be seen as a manager of plant data and relationships in a logical but abstract sense which takes no account of the geometric properties of the plant. Plant geometry and its design and data management consequences are the concern of the second system to be considered, PDMS.

PDMS

The principal feature of PDMS is its construction under designer control of a full-size three-dimensional computer model of the plant layout, held in a database. The model can contain all components — structure, equipment, piping, cabling, ducting, access areas etc. — which take up space in the plant. The layout designer must arrange these components in the space available and must exercise judgment on which components have the greatest claim on available space. PDMS provides the designer with two principal aids at this stage:

- graphical — a picture of the model in the database can be drawn from any viewpoint (Fig. 6)
- logical — clashes between any two components interfering with each other can be detected.

As the three-dimensional layout progresses, the piping is added in increasing detail according to the requirements of the P&ID. Although piping is the principal concern of PDMS, all other layout-related data from other disciplines is input to the PDMS model to ensure that the final plant layout is fully co-ordinated and error-free.

To make the computer model usable and useful to designers and management, the PDMS database also stores properties and relationships of the plant and piping components. PDMS is generally concerned with those properties defining dimensions, positions, identities etc. necessary for three-dimensional modelling, and with the relationships defined for piping design organisation. Reports necessary for piping design and management which combine data on component properties, dimensions and relationships can be produced from the database in familiar formats: nozzle schedules, pipe schedules, valve schedules, material quantities etc.

When the plant, and piping layout, is completed, conventional engineering drawings (for example Fig. 7) can be produced automatically from the database to link the design model with the drafting phase. This linkage can be pursued further through PDMS interfaces to piping detail drafting and material management systems such as COMPAID or ISOPEDAC to convey information from the design model through drafting into the management phase.

PDMS users report (Ref. 2) generally favourable reactions to the system facilities, particularly:

- manhour savings — significant, but not the major benefit
- improvement of information fed into the management phase for fabrication, construction etc.
- improved plant records
- interference detection, saving on-site trouble and expense
- improved drawings and new forms of drawings especially suited to construction.

PDMS is, therefore, a means of linking the design concept to the three-dimensional design model and managing plant space, geometry and data in both a logical and physical sense. The system linkages into the management phase for manufacture and construction of piping introduce an element of CAM for the first time into plant engineering.

Possible future developments

Although these (and probably other similar) systems have found acceptance on commercial-benefit grounds, their true significance is the reasonably advanced degree to which they fulfil the aims set out for 'ideal' CAD techniques of plant design. Much remains to be done to produce the 'ideal'; how much can be gauged by considering that the PDMS data represents, perhaps, only 5% of the total data needed to define the plant and manage its design. Current PDMS projects have databases around 100 Mbytes, which must be held in active store and available for interactive access at all times. The computer equipment and software strategies required for an interactive data access management problem of 400 Mbytes will almost certainly become readily available in the medium-term future, and will enable a fully integrated plant engineering system to be conceived and implemented.

How quickly such a system can be postulated will probably be determined by progress in the database area. Whether a single, unitary database can be structured to contain, for all plant components, their properties and all their potential relationships is not yet clear. Current practice has found separate partial databases to be more practical and economical in software and computing terms, as experience with PEGS and PDMS has shown. Progress towards unifying these partial databases has, so far, been limited to inter-system data transfer at the input/output language level. Direct database-to-database information transfer is possible, but has not yet been achieved. However, this method of system design probably offers more promise in the short term than the unitary database concept.

Engineers in design and management have an important role in database development, which they must recognise. As databases (even for partial database systems) become more complex and contain more data, rapid and meaningful access to designer-selected parts of the data becomes an important factor in the effective use of a system. The fastest and most powerful access means is through a data hierarchy, embodied in the database structure. The hierarchy must, however, relate primarily to the design or management task for which the computer system and database are used. Specification of the design/data hierarchy is thus the direct responsibility of the engineer, based on his knowledge of the engineering pro-

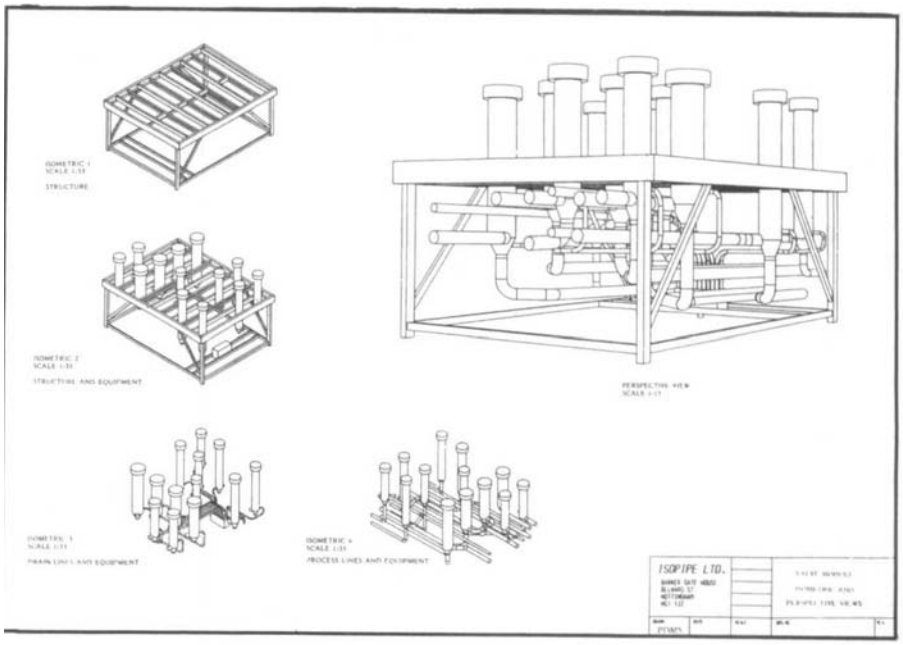

Fig. 6 Process plant layout — pictorial views

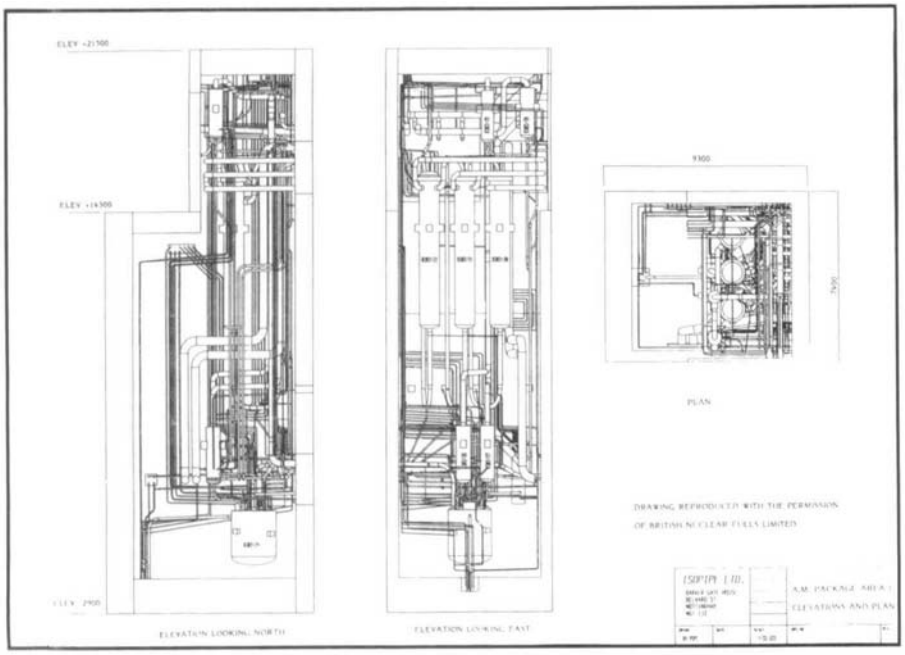

Fig. 7 Process plant layout — elevation

cess, which must be conveyed to the computer system specialist to ensure that the system will work properly in an engineering environment. Successful single-purpose design systems have been produced with effective single-purpose hierarchies, but the development of integrated systems combining several design/data hierarchies with a single database has not yet been achieved.

Trends in computer equipment can be discerned in the workstations already available, which employ microcomputer technology to provide low-cost devices with considerable local computing power for graphics and data processing. Use of these devices may well remove large parts of such activities as problem solving, graphics and specialist data handling from the central computer. If appropriate software and database methods emerge, the central computer may then be able to handle data volumes of total integrated plant design proportions.

Preparing for the future

The benefits of present-day computer techniques are sufficiently recognised to ensure that development will continue towards integrated systems and more sophisticated hardware. Future techniques of design, drafting and information handling will be radically different from those now practised by traditionally trained engineers in conventional design offices. Changes in training, attitudes and management will be needed if engineers are to control the new technology and their professional future. Aspects of plant engineering which merit careful study and preparation for change are as follows:

- *Education:* Future students will have seen computers, VDUs and electronic games from childhood. They will need to use complex, industrial-scale computing in higher education as a precursor to industrial careers. Present emphasis on scientific programming languages and problem solving should expand to include data handling. Could the use of graphics and drafting systems replace the time consuming learning of drafting skills? The industry must help — by making programs and systems available to educators and by releasing practising engineers and managers to assist in engineering courses. Mid-career courses to update the skills and knowledge of practising engineers in computing technology must be developed by universities and the industry.
- *Engineers:* Engineers must regard computers and systems as their professional tools, and use them to improve productivity in the engineering process. Faster design turnround will mean that a larger number of jobs are simultaneously in the designer's mind, competing for his attention, judgment and creativity. However, much less detailed work in extracting and checking data will be required. Computing will encourage creativity and allow designers to create and evaluate more alternative solutions in a more rational, more numerate manner. However, computer techniques even today tend to mask unreasonable answers, and engineers must retain a firm grasp of basics and cultivate a critical approach to computer answers to trap absurdities.
- *Managers:* Managers will have better information, available more quickly, more obviously relevant to the design and more useful in transforming the design into a plant. Budgets and timescales will be correspondingly tighter, and management is not likely to be an easier task — even though it will be better informed. Increased capital invested in computers and systems will demand more attention from design management to smooth peak loads and maintain technical and production standards. Inevitably, more attention will be required in a non-computerisable area: the management and motivation of intelligent, educated people.

The process industry

Plant design and construction will be faster and cheaper in real terms; hence the industry's efficiency in utilising capital can be increased. Better documentation of plant for statutory, operational and maintenance purposes will be available. Facilities will become available to improve design to minimise noise and pollution; perhaps the major advance will be in hazard analysis. In this area, increasing public concern will probably demand that the reasoning and methods underlying adoption of a particular design be recorded, together with the reasons for rejecting alternatives. The combination of public pressures (expressed through legislation) and availability of more powerful hazard analysis techniques may well lead the industry to a similar situation as exists in the aeronautical industry, where external validation of sophisticated engineering technology has improved public confidence in the integrity of the industry and its products.

The process industry will be served in the future by engineers who will be working in a more critical social environment, and they will need the best design and management techniques. To improve these techniques will not be easy; it will require engineers and managers to cultivate an innovative approach to the practice of engineering. The industry and its managers, in particular, must recognise that innovation is difficult, costly and fallible. It is, however, the industry's only hope of survival, and innovators must be encouraged and supported so that we can look forward to the computer-based integration of plant engineering.

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