COMPUTER AID IN THE DEVELOPMENT OF CONSTRUCTION PLANNING AND MANUFACTURING PROCESS IN FACTORIES AND ON SITE

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1. Application of information technology to the construction process

Both the fact that a great many parties are involved in a construction project and that a building consists of numerous technical systems and vast amounts of materials and equipment seem to indicate that there is a great need for data creation, data processing, data transmission and storage.

Information technology is an excellent help in managing data sets of this magnitude. Its application to the entire construction project is presented in Fig. 1.

Services offered by information technology to the construction project are:

- data collection and storage in databases and files
- data transmission via telephone networks, local area networks, disks or tapes
- data processing in modelling the building, in video montages, etc.
- data processing in calculations needed for dimensioning, cost estimation, comparison and optimization
- data processing and data output in the form of drawings, texts and as graphical presentation
- storage and use of expert knowledge concerning design, construction and maintenance by means of expert systems.

The development of computer-aided design and the time-table for its proliferation is presented in Fig 2, in which the degree of use describes shares of different design tasks carried out by means of computers. Figs. 3, 4 and 5 show the development stages of utilization of information technology in design, construction and facilities management.

Advantages gained from using computer aids in different construction phases are listed in Table 1. The table also describes a new design methodology, in which:

- the designer has more time for creative work including evaluation of alternatives and optimization
- general technical and economic background information on building materials and manufacturing methods is obtained from data files and databases
- the designer utilizes the general data in the production of project-specific new data as well as in the results of the creative design process
- computers execute the design routines, store, transfer and output the produced data to different parties.

The chief designer, as shown in Table 1, may be an architect, a process engineer or a structural engineer, for example; however, he must also attend to the duties of his own particular engineering responsibility. Other designers referred to in Table 1 are designers in their own engineering fields.

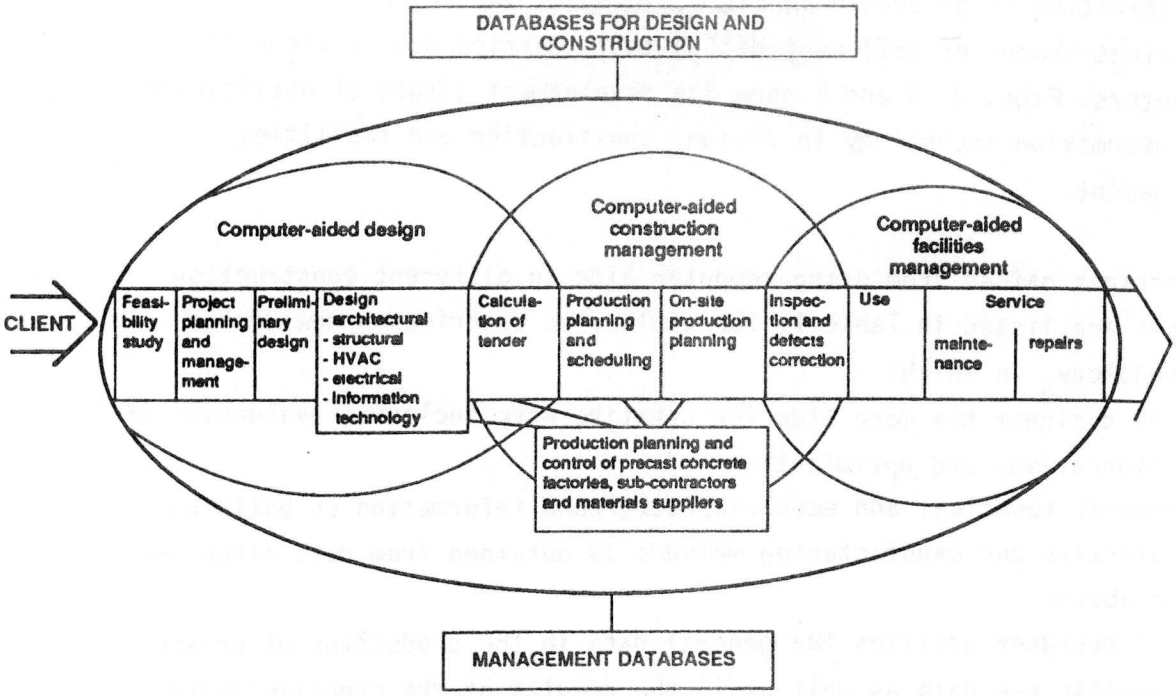

Fig. 1. Diagram of the use of information technology in the construction process.

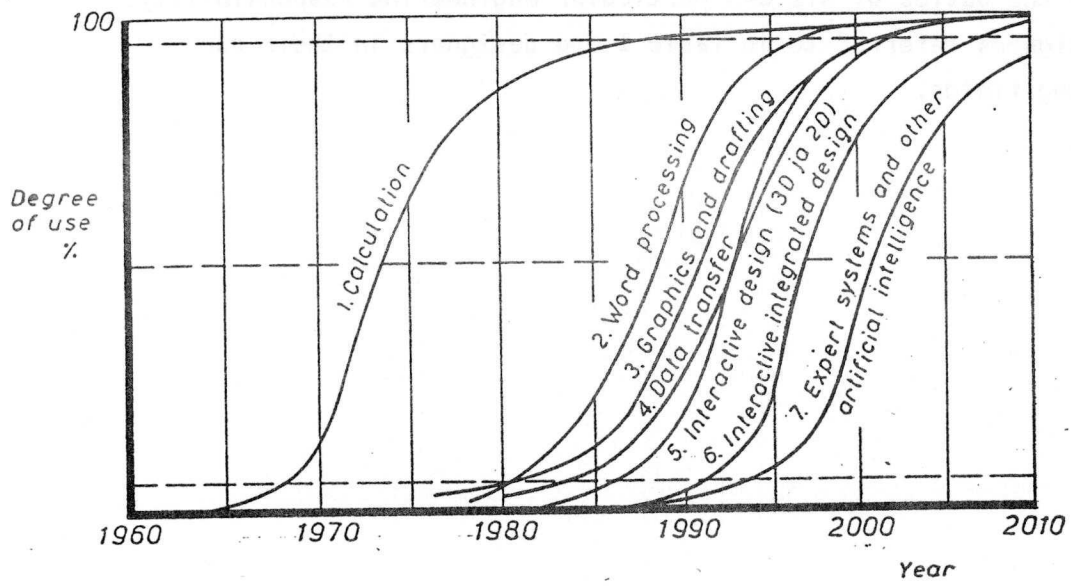

Fig. 2. Development stages in the utilization of information technology in design.

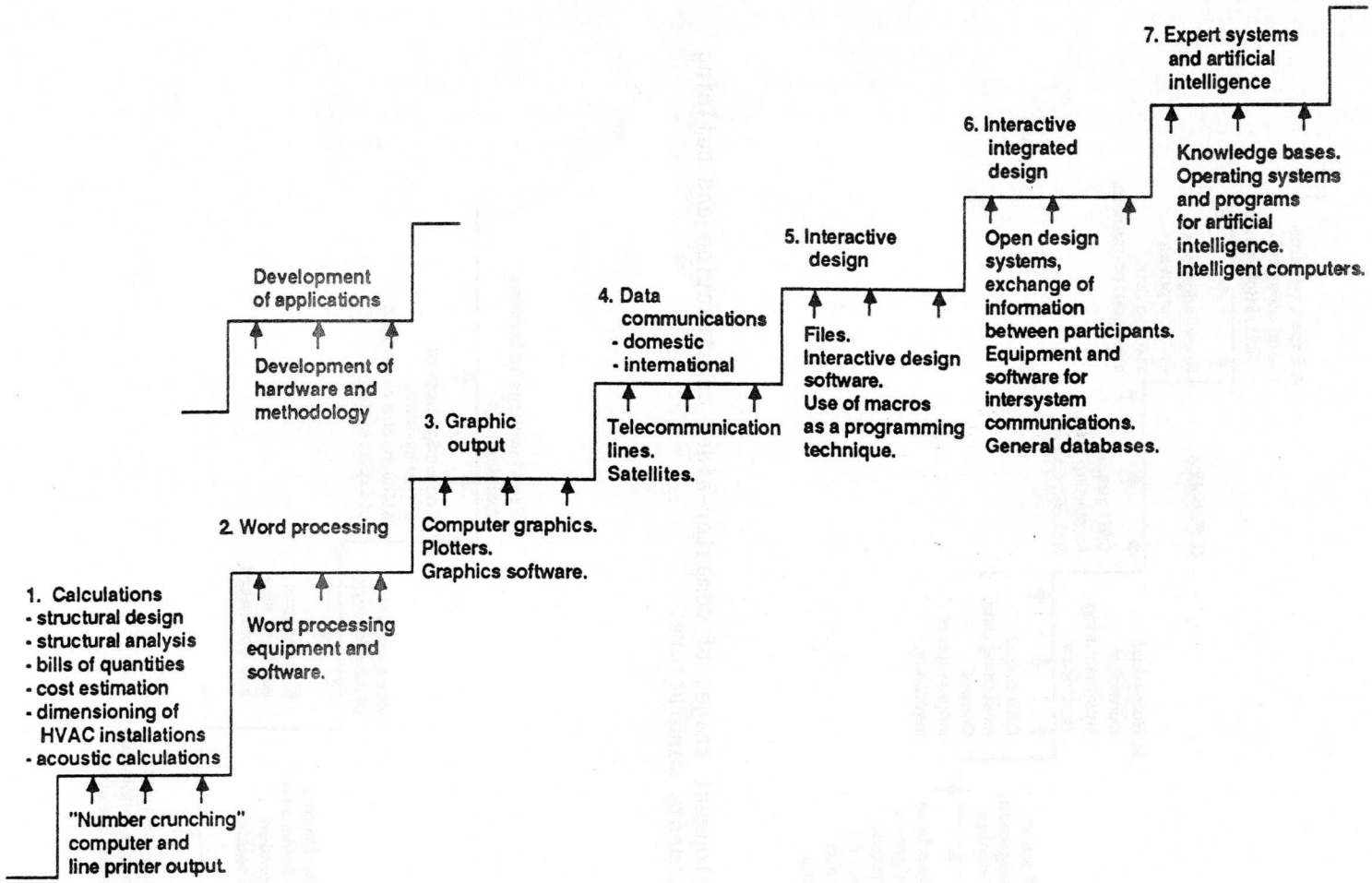

Fig. 3. Development stages of computer-aided design.

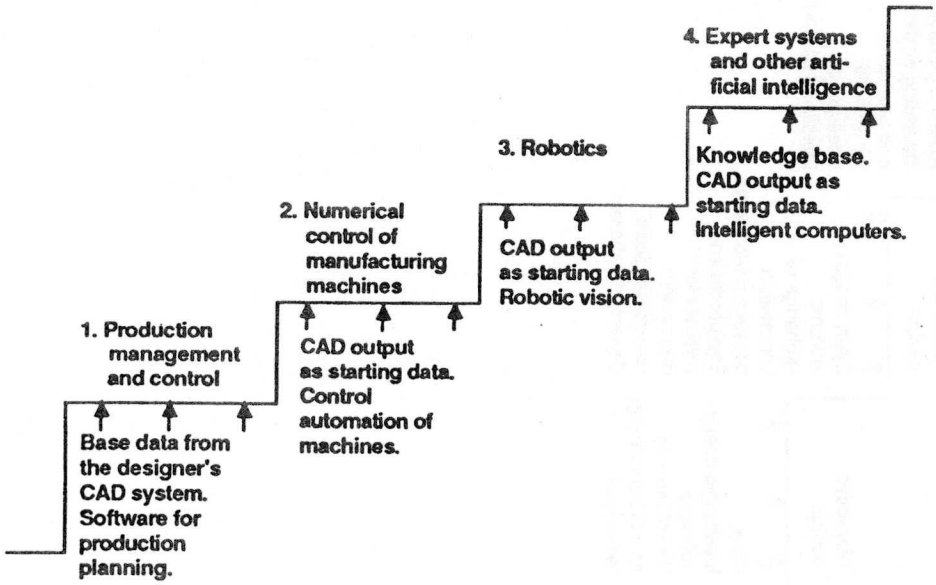

Fig. 4. Development stages of computer-aided construction and building components manufacture.

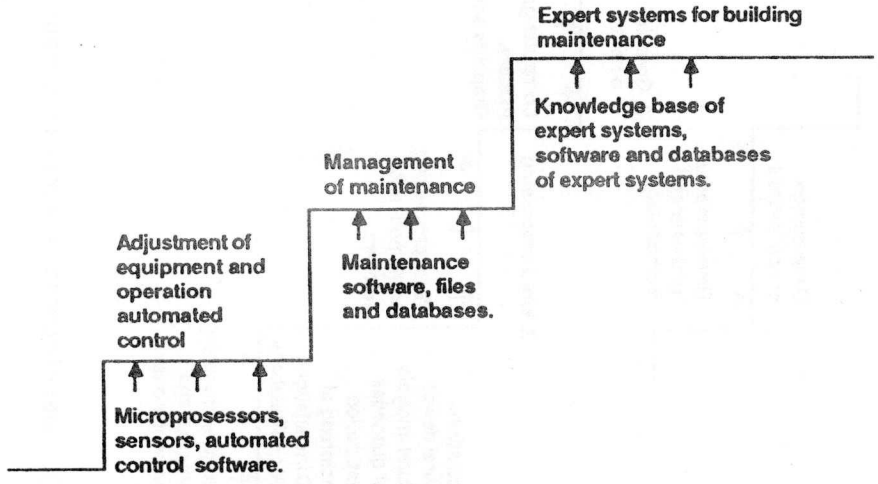

Fig. 5. Development stages of information technology applied to facilities management.

Table 1. Flow chart of computer-aided design and construction management.

ACTIVITIES					DESIGN ORGANIZATION Participation of different parties in design					
PHASE OF CONSTRUCTION PROJECT	DEGREE OF FREEDOM: CREATIVENESS	DEGREE OF FREEDOM: FREEDOM OF CHOICE	BENEFIT FROM CAD	STANDARD FILES	Project leader	Chief designer	Other designers	Contractor	User (occupant)	Other user
1. PROJECT PLANNING AND PRELIMINARY DESIGN			Cost estimates, reference data illustrated with pictures	Important standard costs given as data and data for reference project						
2. INNOVATIVE PHASE			creation of alternatives; exact description; objective comparisons	of little importance, regulations may be needed; data for the dimensioning of space and fixtures						
3 a. DRAFTING PHASE			Editing of plans; constructibility considerations; economical optimization; utilization of files concerning use and maintenance	data of different designers; constructibility data; costs; main measurements; feedback files of use and maintenance and on average use of materials, etc.						
3 b. BUILDING PERMIT			automatic output; expert systems	building regulations						
4. DESIGN			manufacturing pictures not all details; possible alternative results; bills of quantites data for construction; transfer of results to construction site for work planning by CAD	general systems data; product data with pictures, cost data; specifications; basic knowledge of the project; feedback data						
5. FINAL DESIGN			design output directly to site work planning; details optimized for construction method	details suitable for production; specifications for each construction method; feedback data						
5 a. OCCUPATION			editing of building user instructions; feedback information on defects to designers	instructions for use and maintenance						
6. USE AND MAINTENANCE			feedback data and basic information for design; expert system	instructions for use and maintenance						

= very much
= much
= little

= participation at full capacity
= periodical participaton, assisted by

2. A model for the design process

2.1 General

The introduction of computer-aided design causes changes in the design process compared with traditional manual design. From the very beginning the design process must be defined unambiguously, since a machine cannot accept inaccuracies. The plan, composed of the design database existing in the computer files, continuously develops as the design progresses. No files, belonging to the initial stage, which are concerned with the alternatives to be chosen for the later stages, are "thrown away" as is usually the case with the first draughts and sketches in manual design. Computer-aided design is such a process, which stops only for checking purposes.

The design database of a project is defined as all design files of the project together. The use of computers makes the documentation of design more continuous than today, since the real time system enables the various designers to continuously access the database. In this way the haste which in current practice typically precedes design completion deadline and the resulting mistakes can be avoided.

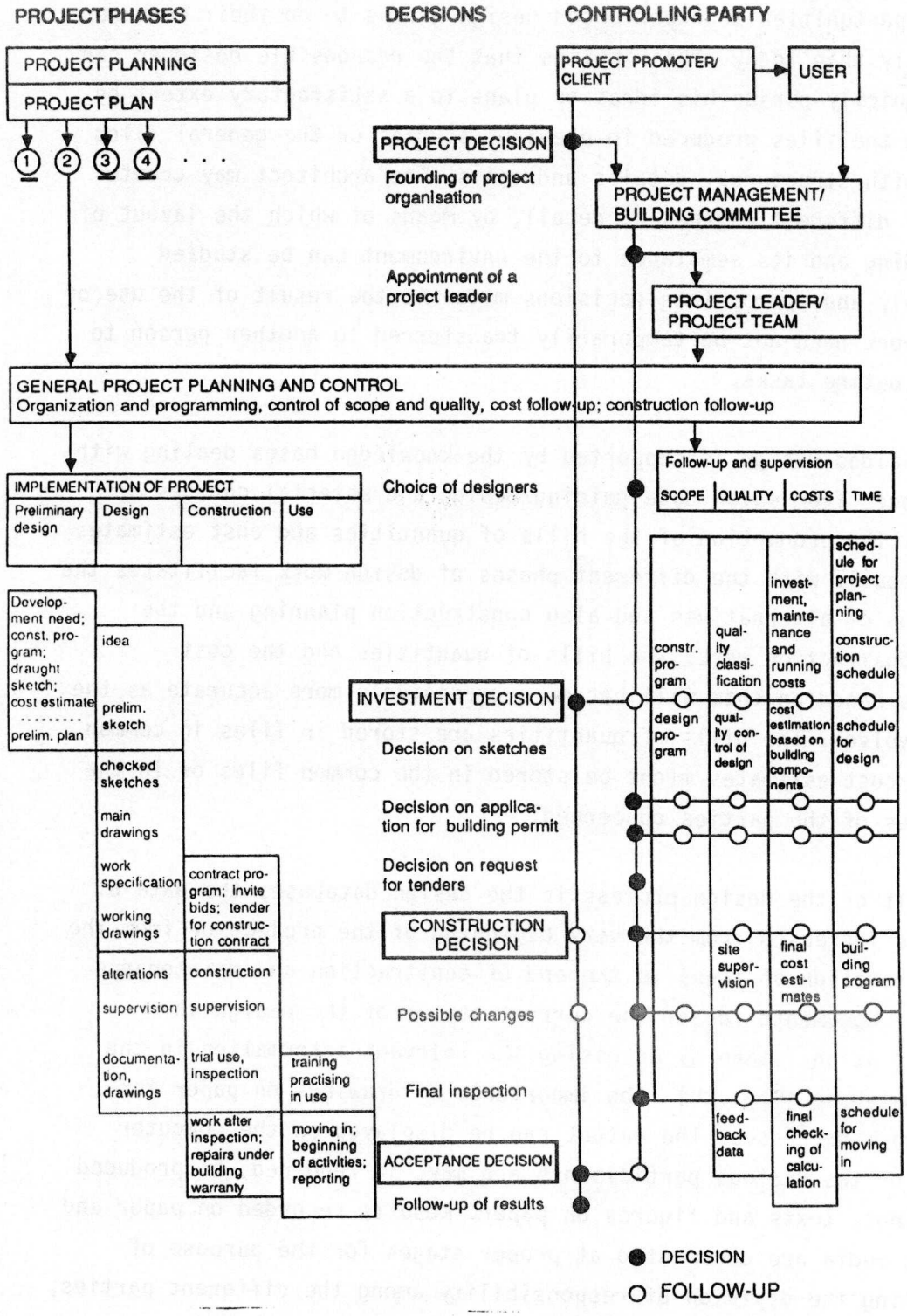

Fig. 6. Diagram of the management of a building project.

A real advantage gained from the use of computers is that it gives better opportunities to experienced design groups to do their work more efficiently than today. This implies that the responsible designer can himself quickly pursue his ideas or plans to a satisfactory extent by utilizing the files produced in previous studies or the general files dealing with structures, details and costs. The architect may create models of different degrees of detail, by means of which the layout of the building and its semblance to the environment can be studied effectively and appropriate decisions made. As the result of the use of CAD the work need not be temporarily transferred to another person to perform routine tasks.

Computer-aided design is supported by the knowledge bases dealing with maintenance, from which data guiding design and material choices are obtained. The production of the bills of quantities and cost estimates simultaneously with the different phases of design work facilitates the comparison of alternatives and also construction planning and the actual construction work. The bills of quantities and the cost estimates based on them will become progressively more accurate as the design evolves. The bills of quantities are stored in files in common use; the cost estimates might be stored in the common files or in the work files of the parties concerned.

The result of the design process is the design database, the data of which has increased from the very beginning of the project or from the first generation of ideas to the end of construction and maintenance planning. Documentation of the current status of the design is available at any stage by accessing the relevant information in the design database (Fig. 10). The importance of drawings on paper for design work decreases. The output can be displayed on the computer screens of the various participants and may, if required, be produced as drawings, texts and figures on paper. Results recorded on paper and computer media are documented at proper stages for the purpose of determining the division of responsibility among the different parties, for possible re-checking of the results and for needs during maintenance operations.

2.2 Model for the design process and outputs in different phases

The model for computer-aided design is presented in Fig. 7. In the boxes at the top of the figure the design-controlling decisions are given, with their essential contents. In the first box on the left the client's project planning and preliminary design phases are completed, in which he has decided to acquire the required space by constructing. At the end of these phases the background information and design instructions are given to an appointed designer.

Innovative phase

This is regarded as the most important phase from the point of view of the final construction result. One of the alternatives, to be developed further, is chosen from those created during this phase. Subsequent to this phase the central aims and choices of the project have been defined. The most experienced designers from every relevant profession participate in this innovative phase. The duties of the designers are to generate an idea and to apply it to the object in question and then to present a preliminary draught sketch of one or several of the alternatives.

The result of the innovative phase comprises one or several well-grounded design proposals and their technical and economic comparisons and cost estimates. The documentation should be descriptive and easily understood. In addition to traditional drawings, descriptive 3-D models and video montages showing the building in its future surroundings are produced for the client's decision-making.

Computers can thus assist in visualizing the ideas of creative design and implementation alternatives much more effectively, and from more varied viewpoints than can the traditional procedures. This is of advantage to both the decision-makers and the designers.

Targets set for the project can be altered during the decision-making at the end of the innovative phase, if the preliminary plans give rise to it.

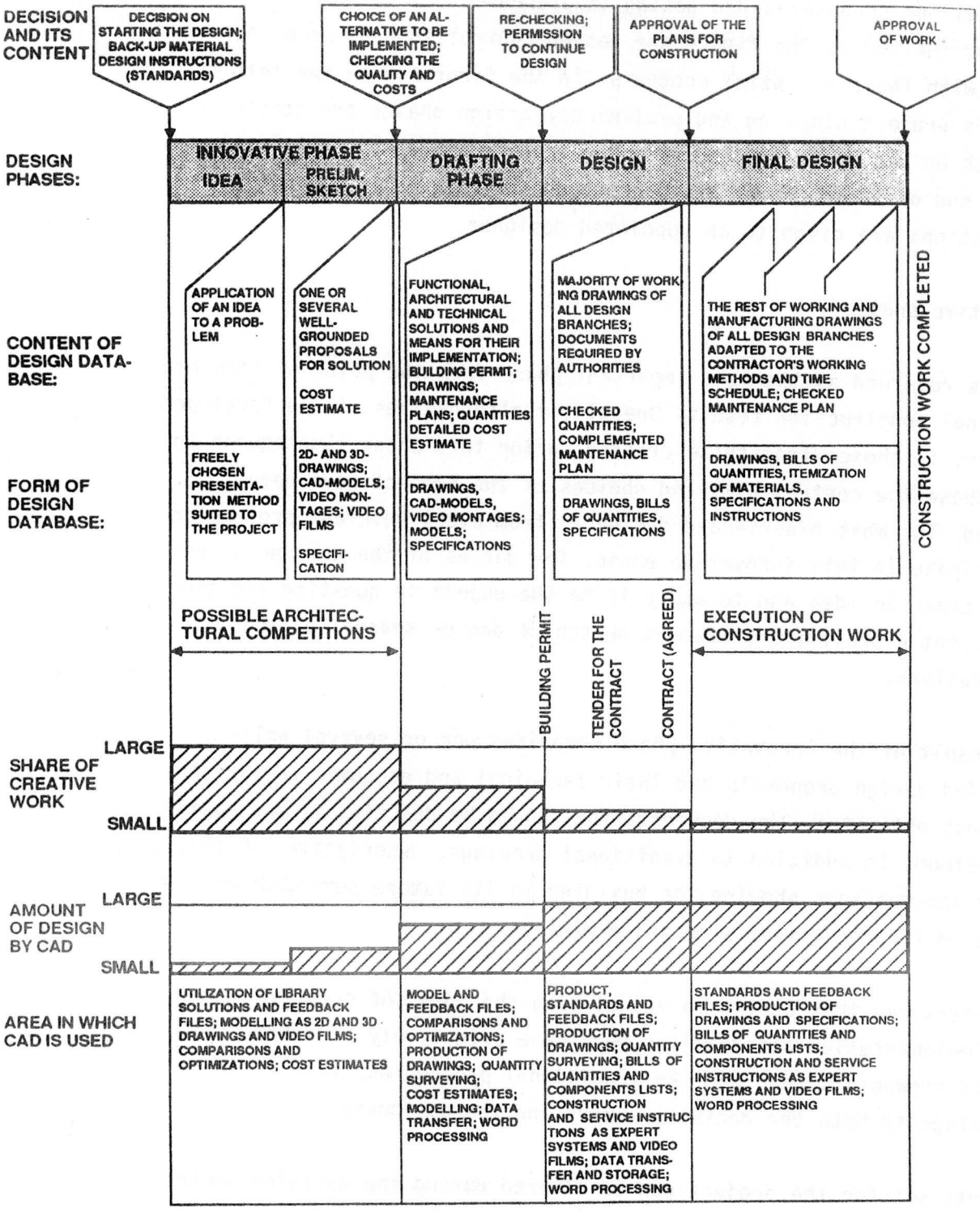

Fig. 7. Model for the computer-aided design process.

Drafting phase

In this phase the chosen alternative is developed so that it exactly defines the construction object according to the client's wishes. At the end of the phase the solution has in principle already been developed to a complete plan. The functionality of the building has been studied on the level of individual spaces, the architectural solutions and main details have been defined, and all the technical solutions are adjusted to meet the overall design requirements. The means to be used in the implementation of these solutions are also discussed. The preliminary plan for maintenance of the building is worked out in co-operation with experts in facilities management. All the designers, manufacturers and other parties involved in the construction project take part in the work of the drafting phase. In this way all expert knowledge is put to a productive use.

At the end of the drafting phase final decisions are made on the extent of the building, its shape, its layout and the quality of equipment. Preliminary decisions are made on the structural frame and HVAC systems.

As a basis for decision-making the functional, architectural and technical solutions, the maintenance plan, the quantities and a cost estimate are documented. The documents are presented in a more precise form than the drawings and specifications of the earlier phases; together with more elaborate 3-D models and video montages. The majority of the documents necessary for official permits are produced or could be produced in this phase.

Design

After possible changes have been made at the end of the drafting phase and a permission for continuation is obtained, work in all design disciplines is started at full capacity. In computer-aided design this means that the design database of the project is rapidly increasing as all the designers are working simultaneously.

The majority of detail and working drawings in all design desciplines are prepared, work specifications are written; dimensioning and technical solutions as well as the quantities, cost estimates and maintenance plans are checked.

This technical work phase which also consists of routine activities means effective utilization of computers in preparing the plans, bills of quantities, cost estimates and work specifications as well as in data transfer. The results of this phase also include the main part of the building's maintenance plan at the necessary degree of detail.

By the 1990's the results of the design phase will also include instructions for construction and maintenance in the form of expert systems and video presentations. The applications are based on general expert systems which are supplemented with data for the building under construction.

Final design

In this phase the final working, detail and manufacturing drawings are produced. These are adapted to the work methods of the contractor and to other firm-specific standards. This phase also covers the transfer of design data to the site and to manufacturing plants. All plans including details are completed in co-operation with the contractor.

The maintenance plan of the building is further developed in co-operation with the designers, contractors and the client. The maintenance plan is checked once more at the end of the construction phase, since part of the maintenance plan content is still being determined in conjunction with material acquisitions.

The result of the design for construction is composed of drawings, bills of quantities, components and materials lists together with instructions for work. These are all in the form of files which the contractor can utilize during the construction to whatever extent he requires. Expert systems and video resources are also used for describing difficult construction and maintenance operations.

The results of this design phase are stored as documents, confirmed by the designers, for the purpose of determining the division of responsibility in the case of claims and for future use during maintenance operations.

3. Utilization of information technology in the design process

The possibilities offered by information technology and computer-aided design for different design phases from project planning to design for construction within the next 5 to 10 years are presented in the form of a list below:

Project planning and preliminary design

- Use of files:
  - Computerized maps
  - municipal site, street, sewer registers, etc. databases
  - room and other standard files organized by function, for example a room data record with basic information and the files dealing with the use, service and maintenance of a building, including costs
  - comparison of the costs of alternative design and design optimization
  - knowledge bases concerning basic data of the functions of different types of buildings. Their use together with expert systems in the layout design and technical and economical optimization.

Innovative phase

- Visualization and modelling of creative design by means of 2-D and 3-D models and video resources
- comparison and analysis of investment, operation and maintenance costs, calculation procedures using computer programs and artificial intelligence
- data transfer between different participants in the design process; organization of the integrated design database and each firm's own work files

- cost estimates and analysis based on the chosen quality levels for rooms and fittings
- feedback databases and expert systems supplementing feedback data
- preliminary estimates of cost ranges and cost risks
- materials and product files, which include basic technical and cost information
- general purpose files and databases, which contain models for designs and work specifications together with official standards
- knowledge bases and expert systems for the preliminary selection and comparison of alternatives.

Drafting phase

- Programs for the comparison and optimization of solutions included in a chosen alternative
- graphic programs for the production of drawings (and bills of quantities) pertaining to a particular design discipline
- production of bills of quantities for the different design disciplines as well as the combined bills of quantities collected in the chief designer's file
- preparation of the cost estimate
- modelling of a chosen and developed solution and its visualization by means of 3-D models and video resources
- programs for preparation of the maintenance plan and maintenance files
- documents required by the authorities. In the production of these binding regulations expert systems may be used
- expert systems of the basic solutions for maintenance planning and maintenance operations
- feedback databases of production and maintenance and the expert systems utilizing these
- word processing
- data transfer between the parties in the construction project.

Design

- General and individual graphic programs for the preparation of drawings and video materials

- calculation of bills of quantities and components lists and systematic output of these
- programs for maintenance planning and maintenance files
- word processing
- data transfer between the different parties in the construction project
- materials and product selection based on materials databases and expert systems
- detail design based on library data as back-up material
- utilization of feedback data of production and maintenance in design by means of feedback databases and expert systems
- data transfer directly from the designer's data files to the files of the construction firm and manufacturing plants.

Final design

- Programs for the production of custom-made design documents for the contractor's different needs; for planning
  - materials procurements
  - individual work tasks

  and for structuring the data according to materials
- the use of the contractor's standard libraries in the adaptation of plans to his methods and products
- the client's programs for the follow-up of construction work
- the programs of the building inspection authorities for checking and approving the implementation plans
- materials and product selection programs for the site, based on expert systems
- representation of difficult construction operations and installations by video resources
- transfer of output directly from the designers' files to the files of the construction firm, manufacturing plants and building sites
- necessary detailing and revisions of the plans during the construction phase in co-operation with the contractors
- graphic programs for visualization of work phase planning, programs for scheduling and cost planning as well as the work instruction files and expert systems.

4. The construction process

4.1 General

Several parties are involved in the construction process:

- a construction firm
- sub-contractors for building services, (e.g. heating, ventilation, air conditioning, electricity and information technology systems) and in other fields
- producers of prefabricated elements
- materials manufacturers
- wholesale dealers.

Each of these have requirements on the other parties in a construction project, primarily on designers. The designers produce new data throughout the entire design period, which increase the project database (Fig. 8). This database is used by the various parties and authorities involved in the construction, through their computers.

The main aspects of the utilization of computer-aided design in the construction process are as follows:

- The project plans are obtainable from files, to which the contractor has access through his own computers available both in the firm's office and on the building site.
- The drawings, specifications and instructions for construction work together with different lists needed during construction are outputted on site in a form suited to each individual need.
- The bills of quantities arranged in different ways are obtainable from files, and these data can be used directly as input data in production planning and control.
- In the design for construction and in the structural solutions the standard solutions and the methods of the contractor in question can be taken into consideration provided they fulfil the quality requirements defined for the final product.
- General material and product files together with knowledge bases can be utilized in interactive design and expert systems.
- Difficult installation and manufacturing instructions can be easily visualized by 3-D models and video facilities.

- Work specifications are presented clearly by modifying in a concise form standard specifications so that they are appropriate to the project in question.
- The factories and construction sites can directly utilize the output data of the design database as input data for their production planning software.

4.2 Information need in different phases of construction

Fig. 8 shows which data in the design database should be accessible to the contractor in different production phases and what further information each production phase produces for the design database of a project.

In Fig. 8 on the right side of the large box, which describes the design database, the information needed from the design database in each phase is listed. Inside the large box on the left side the parts of the design file produced by different activities are presented. In the small boxes the corresponding information is described.

4.3 Preliminary model for computer-aided construction management

Construction covers different phases from tender calculation to actual construction work as shown in Fig. 8 on the right side. These phases include the following:

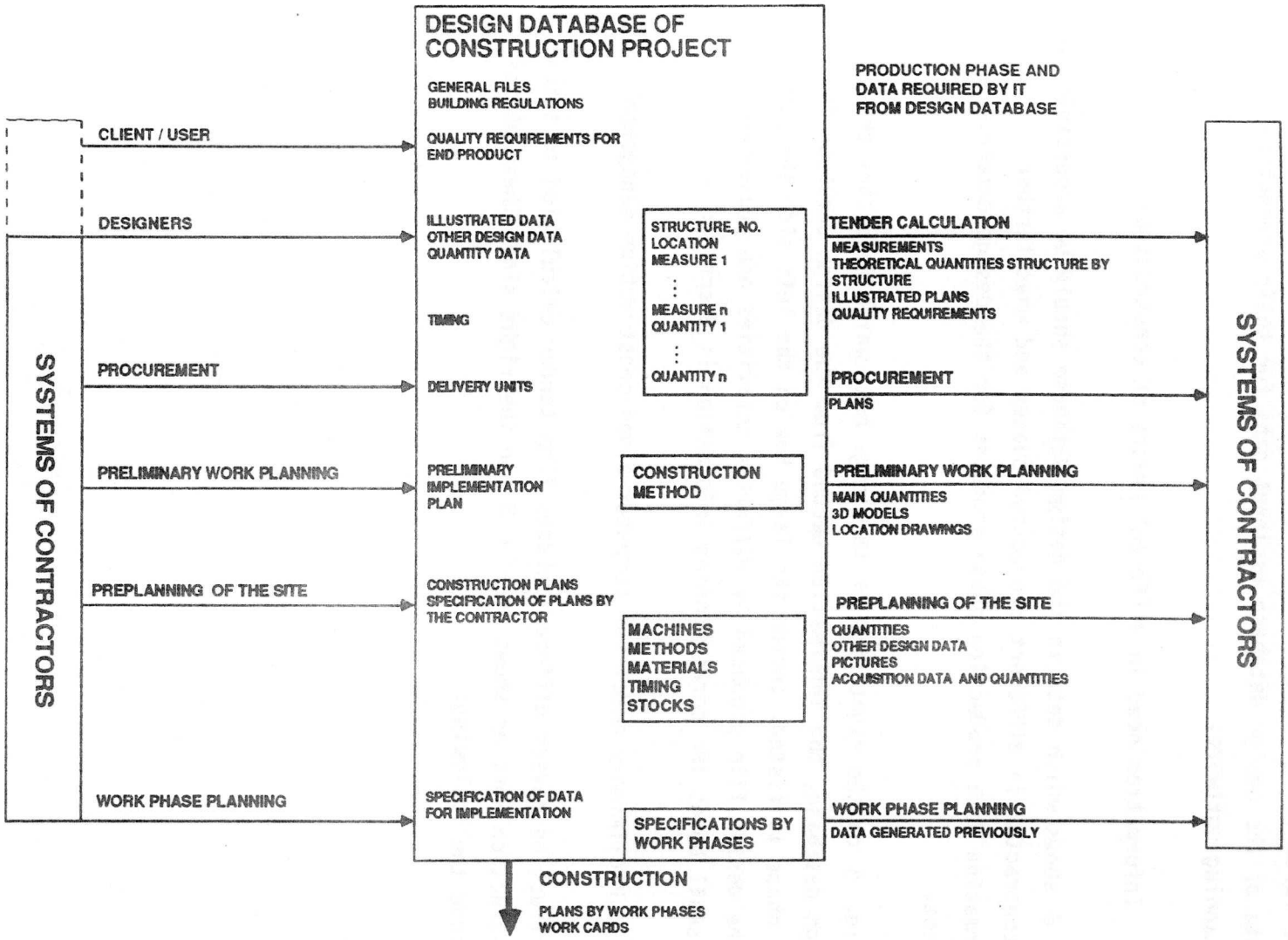

Fig. 8. Design database content and its accumulation.

Tender calculation

Essential information in the tendering phase is concerned with itemized quantities. The quantities, which are used for the pricing of the job, are taken from the design files in the required format. Quantities can be combined and quantities fulfilling certain criteria sorted. The estimator of a tender uses the designer's theoretical quantities as a basis for his more detailed bills of quantities and pricing.

Graphic data is used as a basis for selecting the construction methods, working methods, etc., and through this selection in the fixing of the price. The determination of the price is also affected by other factors such as quality requirements and special instructions given by the designers.

Procurements

In order to plan materials procurements different sets of acquisitions are determined from the quantity data in the designers' plans. The materials suppliers and sub-contractors add their own more specific information to these, which is registered as information related to the acquisition in question. The information about the delivery times and delivery lots, etc. utilized later in work plans, is added to the acquisition data.

The plans for prefabricated building elements together with delivery dates are transferred to the computers of the suppliers.

Preliminary work planning

At this stage information concerning the methods for carrying out construction work is added to the design database. This information also includes the additional plans which the contractor makes.

These additional plans remain in the contractor's file at this stage. This results in a preliminary implementation plan.

Output of quantity data is grouped in such a way as to give the principal dimensions, volumes and surface areas of the different parts of the building. The consumption of principal materials is estimated. The building and difficult stages of work can be described by 3-D models and video materials used as an aid in work planning. The service areas, storage areas and roads on the construction site are planned as well as the weights and measurements of the prefabricated units.

Preplanning of the site

At this stage the resources needed in construction are ensured. Data generated previously and obtained in conjunction with acquisitions are utilized, and the location and number of structures together with the construction methods are determined. The client and the designers negotiate about alternative solutions which conform to the methods of the contractors and these data are added to the file. The quality requirements of the final result are checked and further necessary information is added to the file. A check is made to ensure that every working phase is scheduled and that necessary machines, special methods, etc. are available.

Work phase planning

Work phase planning ensures that the work proceeds as planned. The procurements are checked in order to make sure that the quantities as well as the location and the quality requirements are met. The final plans for the implementation of each work phase are made. These plans are structured in accordance with work packages and, in addition to illustrated information and quality data, they include instructions for work performance and descriptions of necessary machines.

Production

Production is understood to mean construction proper which takes place on site or in factories manufacturing prefabricated units.

For production purposes the plans are structured in accordance with the different work phases. These plans also include the quality requirements for the final result and work instructions to help achieve these requirements. For each work phase only the necessary data for the purpose of arriving at the desired final result of this phase are produced from the design database. The plan data finally reaches the person who carries out the work in the form of work cards. The work cards comprise all the information necessary for performance of the work in question.

During the production phase the as-built drawings for the future occupation and maintenance of the building are prepared for all those objects to which these measures will relate. Together with the designers, the maintenance plan for the building is prepared and complemented, and the future operating service personnel are familiarized with their work.

Quality assurance

The client, the designers, contractors and authorities co-operate to formulate the quality assurance plans and plan their implementation. In quality assurance expert systems can be utilized.

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