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Graphical Data Processing in Civil Engineering

Traitement graphique de l'information en génie civil

Grafische Datenverarbeitung im Bauingenieurwesen

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SUMMARY
Graphical data processing in structural engineering lags behind alphanumeric computer applications. Advances in graphics supporting structural analysis and in implementation of presentation methods are contrasted with difficulties in digital modelling of physical objects. Topics for research and development to promote graphical data processing in structural engineering are presented.

RESUME
Le traitement graphique de l'information n'a pas suivi le même rythme de développement que les applications alphanumériques. La réalisation de progrès dans le domaine de la représentation graphique liée à l'analyse des structures se heurte aux difficultés inhérentes à la modélisation sous forme digitale des objets physiques traités. L'auteur cite les thèmes de recherche et de développement les plus prometteurs dans ce domaine, notamment pour les applications de l'ingénieur constructeur.

ZUSAMMENFASSUNG
Die graphische Datenverarbeitung ist hinter den alphanumerischen Anwendungen der Rechner zurückgeblieben. Fortschritte in der graphischen Unterstützung statischer Berechnungsverfahren und in den graphischen Darstellungsmethoden stehen im Gegensatz zu Schwierigkeiten mit den digitalen Modellen physikalischer Objekte. Es werden Themen für Forschungs- und Entwicklungsvorhaben zur Förderung der graphischen Datenverarbeitung im konstruktiven Ingenieurbau angegeben.

1. THE SIGNIFICANCE OF GRAPHICAL DATA PROCESSING

The drawings of Leonardo da Vinci mark the beginning of modern technology. Since that time, drawing has remained the language of engineering. The structural engineer uses diagrams and drawings extensively. Insight into structural behaviour is gained from diagrammatic representations of computational or experimental results, ranging from simple bar charts to perspectives of principal stress conditions in bridge decks and in thick containers. In structural design, which is creative rather than analytical in nature, the engineer relies heavily on sketches and perspectives. The information required on the construction site is transmitted primarily in the form of construction drawings. The production and use of diagrams and drawings is therefore an integral part of structural engineering.

The traditional process of drawing on paper at a drawing board is extremely versatile. Simple tools are used with little effort. The draftsman and the engineer are in complete control of the contents of the drawing. Once the skill has been acquired, relatively few conventions have to be observed in performing the work. All efforts can be concentrated on the contents of the drawing. The traditional method does, however, suffer from the limitation that human effort is required to perform tasks which could potentially be performed by machines:

- Human effort is required to collect the data from which drawings are constructed.
- Human effort is required for purely mechanical tasks in the drafting process, such as shading, lettering, construction of perspective views, enlargements and reductions in size and copying of parts of drawings.
- Human effort is required to collect data from drawings for use in other phases of the construction process.

Graphical data processing on computers offers the opportunity to eliminate some of these limitations. The geometric data and the computational results can, for instance, be used to draw isolines of stress automatically. Care must, however, be taken that this is not done at the cost of restraints on the creative process. In particular, the nature of the available software should not limit the engineer to specific types of structures or behaviour. Computer hardware and software must offer a degree of comprehensiveness and flexibility in graphical data processing which is comparable to that of paper and the drawing board. Where this is not acheived, the engineer is inhibited by the tool and will resist its introduction. The elimination of mechanical tasks is not an adequate compensation for the loss of creative freedom.

The wideranging application of computers to support analysis and text processing in structural engineering is an established fact. Negative influences on structural engineering must be expected if we are not successful in acheiving a comparable level of graphical data processing. Powerful numerical tools and reduced computer costs have already led to heavy emphasis on structural analysis at the cost of reduced emphasis on structural design. Effective methods of graphical data processing are urgently required to restore the balance between structural analysis and design.

2. THE FUNDAMENTAL PROBLEM OF GRAPHICAL DATA PROCESSING

During the last three decades, new technologies have created a wide range of functions for computers and communication networks:

- Collection and presentation of data,
- Storage of data so that they can be automatically processed,
- Processors for logical, numerical, text and control data,
- Transfer of data between devices, locations and persons.

Applications in structural analysis, text processing and machine control have been highly successful. This raises the question why applications in graphical data processing have been less successful. The differences between the development of graphical data processing and other branches of digital data processing must be attributed to very fundamental differences between images and symbols. This is demonstrated by the following examples.

Any given value, for instance the letter E, can be regarded either as a symbol or as an image. The distinction is essential. The symbol E is identified by a unique code, which is defined within the context of a set of symbols. The image E consists of a set of pixels or a set of vectors. These geometric elements individually do not posses a meaning related to the letter E.

The keyboards, printers and terminals of computers contain built-in standard sets of symbols. Symbols are therefore entered and displayed in a computer with minimal effort. The color values of the pixels of an image are also readily scanned and displayed. The recognition of the relationship between the pixels is, however, assocated with considerable effort. This effort increases as more irregular images, eg. the lines of a freehand sketch, are interpreted.

The relationships between symbols differ significantly from the relationships between the geometric elements of an image. As an example, it is noted that the symbols of a text are ordered implicitly from left to right in a line and from top to bottom on a page. Seperators are defined for words as well as sentences. The variables in arthimetic and logical expressions also are related through simple operators and conventions. In contrast herewith, the geometric arrangement of the components of a drawing must be registered explicitly. Seperators comparable to blanks in a text are not available. Thus the plan of an office geometrically consists of a series of polygons. Logically it consists of walls, floor panels, furniture, dimensions and text. The same polygon represents both the edge of the floor and a face of the wall.

These simple considerations point to the fundamental problem of graphical data processing. The symbolic contents of drawings tends to be low compared to that of text and computation. The low percentage of implicit information makes it necessary to store a considerable amount of data explicitly and to apply powerful algorithms to relate and transform these data. The resulting demands on computer hardware and software lie more than one order of magnitude above those for alphanumeric applications. It is not suprising that graphical data processing has lagged far behind other applications of computers in structural engineering.

3. THE STATE OF THE ART

Graphical data processing on computers has not been able to replace the drawing board in structural engineering practice to a significant extent. The development of software packages and individual applications have not yet been followed by general acceptance in the profession. Of a wide variety of graphics packages offered at computer conferences and fairs, only a limited number is specifically suited for structural engineering. Figure 1 shows a summary of such packages offered at the SYSTEMS'81 in München.

In view of the high symbolic contents of diagrams, it is not surprising that efficient graphic tools are available primarily for schematic representations. Typical applications are shown in Figure 2. Structural analysis on computers involves a large volume of input data and computational results. The checking and interpretation of these data without graphics capabilities is tedious and susceptible to error. The functions listed in Fig. 2 are therefore of great practical value in the analysis and evaluation of structural behaviour. Nevertheless, they represent only a small volume when compared to the drawings required in structural engineering

FIDES, München

DLT	Reinforced Concrete Drawings, Reinforcement Lists
EUKLID	Perspectives, Hidden Lines
SHELLS	Shells of Revolution

Prof. Werner, TU München

PLOTSET	Geometry, Displacements, Stresses, Forces, Envelopes

T-PROGRAMM, Reutlingen

STFPLOT	Geometry and Reinforcement of Prefabricated Elements
FEPP1	Geometry, Displacements, Stresses, Temperatures for FEM

RIB, Stuttgart

MENOS	Perspectives, Intersections, Hidden Lines
MINOS	Reinforced Concrete Drawings, Reinforcement Lists
DUPLAZ	Reinforcement Drawings for Floor Slabs
RIBKON	Interactive Drafting for Building Construction

IKOSS, Stuttgart

FEMGEN	Interactive Finite Element Generator
FEMVIEW	Viewing of Nets and Results, Hidden Lines

CALCOMP, Düsseldorf

GTB	Drawings of all Types without Dimensioning
EDS	Technical Drawings with Dimensioning

FIG. 1: Graphics for Structural Engineering at SYSTEMS'81[14]

1. Graphs of a function of a single variable
- Load displacement curves
- Time history of displacements, strains or stresses at selected points in the structure
- Variation of displacement, stress or force on cross-sections and along the axes of structures members.

2. Isolines of a function of two variables
- Lines of equal displacement
- Lines of equal stress or equal min/max principal stress.

3. Presentation of principal values
- Crosses representing direction and magnitude
- Orthogonal nets tangential to the directions of principal stress.

4. Eigenshapes of structures
- Dynamic analysis
- Stability analysis.

5. Influence lines and envelopes
- Frame structures
- Plate structures.

6. Finite element nets on selected surfaces
- Numbering of elements, nodes and materials
- Undeformed and deformed geometry.

7. Projections onto developable surfaces
- Finite element nets
- Isolines
- Crosses of principal stress.

8. Isometric and perspective views
- Validity checks on computational models
- Deformation patterns illustrating structural behaviour.

FIG. 2: Graphical Functions for Schematic Representations

design, particularly the drawings for formwork and reinforcement of concrete structures or the workshop drawings for steel structures.

Graphics software packages have also been developed to support the analysis and design of particular structural elements or of complete structures, eg. floor slabs, beams and columns, cores of high rise buildings, cylindrical tanks and steel frames. These packages tend to be adapted to the requirements of a particular design office or construction company, and to reflect the specific knowhow, organisation, procedures and equipment on which the business of their originators is based. Even such basic components of working drawings as bar shapes, reinforcement mats, prestressing systems and connections for steel structures are standardized to a limited degree only, and companies tend to implement their own specific preferences.

General purpose computer-aided design systems with comprehensive graphic capabilities for a wide range of structural engineering problems are less likely to be developed and accepted in the near future than similar systems in related areas such as automibile engineering, electronics or aerospace engineering. This is documented by the large volume of graphics packages already being offered [14] for computer applications in these industries, which benefit from close ties between computer-aided-design and computer-aided-manufacture, concentration of production in factories and the production of articles in larger numbers than is usual in the building industry. It is, nevertheless, essential to undertake strong efforts to develop graphical data processing in structural design in order to preserve the creativity of structural engineers in the computer environment.

4. TOPICS FOR RESEARCH AND DEVELOPMENT

4.1 Improvements of the Symbolic Contents of Drawings

A primary objective of basic research in graphical data processing is the expansion of the symbolic contents of graphic data. By enlarging the set of available symbols and the volume of information associated with each symbol, the storage requirements for graphics are reduced, the development and maintenance of graphic application packages is facilitated and the portability of the packages between devices, operating systems, manufactures and users is enhanced. The following examples illustrate this type of research:

1. The basic graphical elements and functions are standardized to give them a symbolic character comparable to that of the operands and operators in algebraic or logical expressions. In order to request the operations associated with a particular function, it is sufficient to store the function code and to identify the operands. The operands, in turn, posses standardized attributes comparable to the type and length attributes of algebraic values. Additional functions are defined to set and to modify these attributes. The graphical functions in the Information System of Technology (IST) [1,2,3,4] and the Graphical Kernel System (GKS) are research efforts of this type [5,6,7]. The Graphical Kernel System is summarized in Fig. 3.

2. Groups of basic graphical elements and functions are combined to create higher level graphical functions. These functions are usually independent of specific applications and may be compared to subroutines for the solution of linear systems of equations or eigenvalue problems. Such higher order graphical functions are, for instance, used to plot functions and isolines; draw and annotate axes; hatch specified areas; create representations of space curves, three-dimensional surfaces and intersections; draw projections and perspectives; remove hidden lines and surfaces. These functions, like the basic functions, can be requested by specifying their code and an appropriate set of arguments. Due to the volume of the data involved, it is frequently necessary to define a data structure for the arguments. The graphics display system MOVIE [8] contains functions of this type. It is summarized in Fig. 4.

CONCEPTS

Two-dimensional graphics on vector and raster devices.

Input and output at graphical workstations.

Definition, transformation and administration of pictures.

Intermediate storage of segments independent of workstations.

Long term storage of graphical information in metafiles.

Implementation of functional capabilities in levels

FEATURES

Output primitives:	polyline, polymarker, text, fill area, etc.
Input primitives:	locator, valuator, string, pick, etc.
Input types:	request, sample, event
Segment capability:	Group of primitives with pick identifiers
Operations for segments:	Create, transform, insert, close, rename, delete
Segment attributes:	Visibility, detectability, highlighting, priority
Segment transformations:	Scaling, rotation, translation
Coordinate systems:	World (WC), normalized device (NDC), device (DC)

FIG. 3: Summary of the Graphical Kernel System[5]

CONCEPT

Interactive system to generate and manipulate three-dimensional models consisting of polygonal elements, and to display the models on vector or raster graphics devices.

FEATURES

DISPLAY:	Perspective display of polygonal elements Scaling, translation and rotation of models Removal of hidden lines and surfaces Node and element numbering Coloring, shading and highlighting of images Animation of scaling, translation, rotation, deformation
UTILITY:	Generation and editing of element models File management for geometric, scalar and vector data
TITLE:	Generation of two- and three-dimensional characters
SECTION:	Slicing of models to expose internal surfaces Extraction of surface data for DISPLAY
MOSAIC:	Construction of polygonal elements from contour lines
COMPOSE:	Creation of multiple image line drawings.

FIG. 4: Summary of the Graphics Display System MOVIE[8]

3. Drawings are composed of elements [9]. New methods are being developed to describe the relationships between the elements of a drawing. The elements may, for instance, be associated with fictive layers. By specifying appropriate combinations of layers, it is possible to selectively draw subsets of the total information associated with the drawing. Thus an undeformed finite element net, the deformed finite element net, the numbers of the nodes, the numbers of the elements and the numbers of the materials used may be associated with different layers. It is then possible to determine at execution time whether element numbers are desired or the deformed net is of interest, and to draw the appropriate information by selecting the corresponding layers. In interactice graphics, extensive functions [5] are required to set and pick markers, to set the visibility and detectability of elements of a drawing and to pick, duplicate and transform elements.

4. The classical symbolism of structural engineering is enhanced. Existing conventions for schematic diagrams are generalized, eg. the symbols for bar shapes, bolt diameters, welds and steel profiles. Within each area of application, it is then possible to create additional higher graphical functions for these symbols. Some graphic packages, eg. CADIS [10], contain functions which permit the definition and use of new symbols by the user himself at execution time. Thus the various shapes of T-sections for concrete beams may be treated as variations of a symbol defined by the user. Groups of symbols can be combined to define new, expanded symbols. This could, for instance, be an assembly of T-beams and other elements to form the cross-section of bridge. The logic involved may be compared to that of multi-level subroutines in alphanumeric data processing.

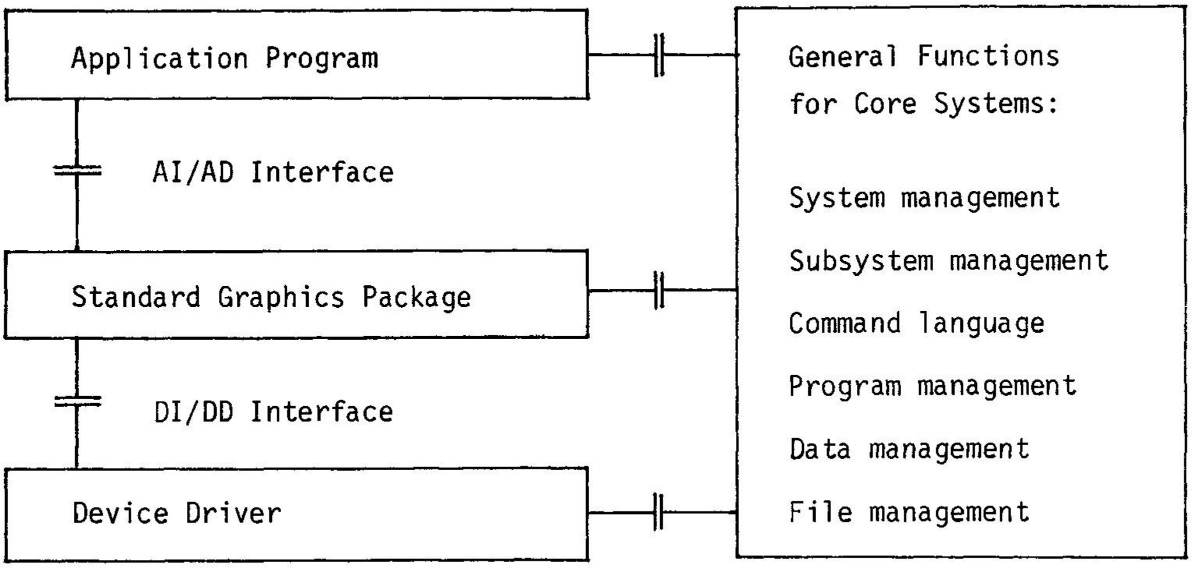
4.2 Advances in Data Technology

Advances in data technology create new opportunities for graphic data processing in structural engineering. As the capabilities of the graphic work stations expand and their integration into the standard software of computer systems is improved, new applications become economically feasible. The following examples illustrate this development:

1. The design, analysis, construction and maintenance of structures posses a common data base. Through this data base, graphic data processing is related to all other aspects of computer-aided structural engineering [1]. Software for graphic data processing should therefore be designed in conjunction with the software used for data and file handling, procedure management, command language interpretation, etc. The modular concept of graphics software is illustrated in Fig. 5. In particular, unnecessary duplication of data management functions in graphics packages should be avoided. Graphic and nongraphic functions should be clearly seperated by defined calls and exits. As well-structured software packages for computer-aided structural engineering with core functions for data and procedure management become available, the implementation of graphics capabilities is greatly simplified.

2. In order to facilitate the interaction between engineer and computer, graphic data processing should be decentralized where possible. The decentralization of functions and devices could be readily implemented if it were associated with a decentralization of the data. Yet a central data base is required for each project in order to assure the coordination of the design process. Local processing therefore demands temporary local files and validity checks when local files are reintegrated into the central file. For example, the reinforcement design of a beam may be accomplished with a local file which becomes part of the central project file unless a project modification at another local workstation has changed the length of the beam while it was being designed. The large volume of data involved, the high rate at which changes tend to be made and the fast response times required for efficient design all place high demands on the operating systems and on the organisation of the design software.

STRUCTURE



OBJECTIVES

Portability of application packages (AI/AD Interface)

Standardization of programming methods (Standard Graphics Package)

Minimization of device dependence (DI/DD Interface)

Portability of graphical representations (Exchangeability of Drivers)

AI/AD: application independent / application dependent

DI/DD: device independent / device dependent

FIG. 5: Modular Graphics Software Systems

3. During interactive design, the engineer frequently decides not to use the results of an analysis or design step because he is not satisfied with the result. He then wishes to return to the status quo ante, and to try a different solution. This is not possible if conventional data technology is applied, since the data base is changed in the execution of the analysis or design step. Efficient methods are required to store temporary intermediate data and to integrate these data into the permanent data base if the design step is successful. The large volume and generalized structure of graphic data complicate the solution of this problem.

4. Applications of interactive graphics in structural engineering have been restricted mainly to individual computers or to local computer networks. In order to avoid the unnecessary effort involved in setting up independent data bases if several companies work on a common project, or if the design is to be checked by the authorities, it is likely that geographically extended networks will be used in the future to transmit drawings or data bases from which drawings are generated at the receiving end. It has not yet been possible to establish national or international standards for graphic metafiles, which are a prerequisite for the successful operation of such global networks with graphical functions. Efforts are, however, under way in connection with plans for a German Research Network [11].

5. Reports in structural engineering are composed of numbers, texts and diagrams. These elements are related through their geometric arrangement, for instance their location on a page. They are also related in their meaning: thus dimensions specified in diagrams are used as input for computations, whereas remarks in a text may influence a construction drawing. Such mixed systems require special data structures, which remain to be developed and to be investigated with respect to their suitability.

6. The capacity and the flexibility of graphical devices for computers are not yet comparable to those of the drawing board. In particular, the market does not offer economical electronic storage media comparable in simplicity, visibility, capacity and changeability to graphite on paper. It is unlikely that plotters, digitizers and storage tubes backed by disk storage will satisfy the full requirements in the near future, since a drawing of 100x100 cm at average resolution already contains on the order of 10^8 Pixels. In order to compensate these deficiencies, efforts are under way to develop methods to compress raster data, for instance by conversion into vector data. The problem lies in the efficient modification of compressed data.

4.3 Digital Models of Structures

The successful application of graphical data processing in structural design depends on the development of simple and efficient digital models for structures [12]. While the geometric relationships between the elements of a drawing describe its syntax, the digital model describes the semantics of the object shown. Thus the digitial model indicates that a particular polygon is to be interpreted as the outline of the cross-section of a beam, whereas geometrically it is simply a sequence of straight lines.

1. Digital models of structures frequently are structured as assemblies of structural elements, each of which is described by a digital model of its own. The digital model of the element describes its geometry and structural properties, whereas the digital model of the complete structure specifies the elements and their location in the structure. Models of this type are suitable for wood and steel structures as well as prefabricated concrete structures. Typical elements of such models are:

- Beams, columns and ties
- Slabs, walls and panels
- Flat plates and foundations
- Reinforcing bars, cages and mats
- Connection plates.

2. If a structure is monolithic, the decomposition into structural elements becomes ambiguous. Thus the slabs, beams and columns of a monolithic concrete frame intersect geometrically, and the same concrete may be used structurally to act both as slab and as flange of the concrete beams. Reinforcement can no longer be associated with individual elements, since it frequently continues between elements. In this case, it can be advantageous to define the digital model of the concrete for the structure as a whole without decomposing it into elements. In such models, a set of nodes, center lines and planes is defined and the structural dimensions are specified with respect to this geometric reference frame. Reinforcement bars, mats and cages are then defined as elements and located with respect to the geometric reference frame.

Considerable research and development effort is required to develop and propagate digital models of structures so that they acheive broad acceptance. Success depends essentially on the simplicity of handling of the models, on their adaptability to the needs of the individual design office, construction company and project and on their interface with other phases of the computer-aided structural analysis and design, architecture and construction.

4.4 Development of New Algorithms

The basic algorithms for graphic presentations are well developed. Nevertheless, improvements remain possible:

1. Some of the algorithms for graphic data processing impose high demands on CPU-time and storage capacity. Typical examples are algorithms for perspective views, for the detection of hidden surfaces and for pixel-vector transformations (recognition of the elements of scanned drawings). Research is being conducted to enhance the efficiency of algorithms for these tasks.

2. As the capabilities of communications networks expand, the gap between technical computer graphics and general image processing will narrow. The development of raster graphics contributes to this trend. Considerable research is required on algorithms for transformations between raster and vector data as well as for correlation between vectors and digital models.

3. Effective algorithms for smooth representations of space curves and space surfaces defined by the coordinates of selected points are of great practical importance. The algorithms for smoothing such curves and surfaces are closely related to the finite element method for the bending of frames and plates. Advances in the finite element method can therefore be transfered to graphic data processing, for instance to the construction of smooth isolines and continuous tone images.

4. In some cases, the algorithms providing the input data for graphical representation can be changed so that their results become more suitable. For example, most finite element systems determine the stresses at selected points in the elements. Algorithms for isolines require nodal stress values. Averaging techniques for the stresses in adjoining elements can lead to loss of accuracy. As an alternative, it is possible to regard the results of a displacement analysis as initial displacements for an analysis based on the Hellinger-Reissner-Priciple, treating the stresses at the nodes as system variables. At the cost of an additional analysis, improved nodal values are obtained directly.

5. CONCLUSIONS

The trends which are presented in this paper lead to the following conclusions about the present state and future perspectives of graphical data processing in structural engineering:

1. Graphics support of structural analysis is well advanced. Particularly the graphical functions for finite element packages have become fairly standardized and are available in a variety of program packages.

2. The digital modelling process in structural engineering must be seperated from the viewing process. Modelling is concerned with the generation of data structures representing the physical object in the computer. Viewing is concerned with the geometric representation of objects whose digital model is stored in the computer.

3. The implementation of the viewing process has been structured and standardized. Basic functions are provided as core functions by systems like GKS, higher functions in standard graphics packages like MOVIE. These interact with the application packages and with the general functions for computer-aided-engineering through well defined interfaces.

4. Graphical data processing in structural design depends on suitable digital models for structural elements and complete structures. Considerable further effort is required in this area.

5. Current trends in the prices and capabilities of graphics devices favor the expansion of decentralized graphical data processing in structural engineering. It cannot be foreseen, however, when the drawing board will be replaced to a significant extend by computer devices.

The evolution of graphical data processing in structural engineering will span several decades. It will be a success if the drawing remains the language of the structural engineer.

REFERENCES

1. PAHL P.J., BEIŁSCHMIDT L., Informationssystem Technik (IST): Programmierhandbuch, IST-Bericht 77/01, Technische Universität Berlin, 1977.

2. GRILL H., RATSCH C., Informationssystem Technik (IST): Grafik Handbuch, Teil I: ISTRAN Anweisungen, IST-Bericht 76/02, Technische Universität Berlin, 1976.

3. GRILL H., KLÖK F., Informationssystem Technik (IST): Grafik Handbuch, Teil II: Kommandos, IST-Bericht 76/03, Technische Universität Berlin, 1976

4. GRILL H., KERL H., Informationssystem Technik (IST): Grafik Handbuch, Teil III: Deklaration von Grafik Geräten, IST-Bericht 76/04, Technische Universität Berlin, 1976.

5. INTERNATIONAL ORGANISATION FOR STANDARDIZATION, Graphical Kernel System (GKS): Functional Description, ISO/TC97/SC5/W62, First Working Draft (Version 6.6), May 1981.

6. BECHLARS J., BUHTZ R., Common Graphics Manager (CGM): Handbook, Freie Universität Berlin, Zentraleinrichtung für Datenverarbeitung, December 1981.

7. NOWACKI H., et.al., Introduction to the use of GKS: Tutorial Lecture Notes, Eurographics'81, TH Darmstadt, September 1981.

8. MOVIE.BYU., A General Purpose Computer Graphics Display System, Brigham Young University, Verion 4.1, June 1981.

9. BEILSCHMIDT L., Grafische Informationsverarbeitung beim Rechnerunterstützten Entwickeln und Konstruieren: Anwendung, VIII. Internationaler Kongress über die Anwendung der Mathematik in den Ingenieurwissenschaften, Weimar, 1978.

10. SIEMENS., CADIS-2D: Computer Aided Design Interactive System, User Manual Nr. U371-J-Z57-1, Postfach 830951, München.

11. Projektvorschlag DEUTSCHES FORSCHUNGSNETZ (DFN), Arbeitskreis Deutsches Forschungsnetz, Hahn-Meitner-Institut, Berlin, June 1982.

12. BENGS H., Rechnergerechte Darstellung von Stahlbetongebäuden, Dissertation, Technical University of Berlin, December 1978.

13. PROCEEDINGS., International Conference on the Application of Computers in Architecture, Building Design and Urban Planning (PARC 79), Ausstellungs-Messe-Kongress-GmbH, Berlin, May 1979.

14. CAD/CAM Katalog., Systems'81, Kernforschungszentrum, Karlsruhe, September 1981.