IT-use in Reinforced Concrete Detailing
The current state, a forecasting-model, a future-concept.

R.A. Chandansing and Ch.J. Vos

Delft University of Technology, Faculty of Civil Engineering, Section for
Concrete Structures,
P.O. Box 5048, 2600 GA Delft, The Netherlands

Abstract
     This contribution to the CIB seminar "The computer integrated future"
describes the current state in the Netherlands, concerning the levels of CAD-
systems used, their diffusion in practice and constraints and effects of their
use for reinforced concrete detailing. An initial forecasting model for the
further development of IT in the concrete construction industry and a future-
concept for IT-use in reinforced concrete detailing are presented as well.

1.   INTRODUCTION

     In 1986 the Delft University of Technology, section for Concrete
Structures started the CADCRETE-program [1]. The aim was to perform research
on the use of CAD-CAM systems in design and construction of concrete
structures. The results and efforts are shared with other universities,
research institutions and the concrete construction industry. This formula is
quite successful, mainly due to the intensive participation of all parties.
     Within the CADCRETE-program a study project was started by the end of
1989 concerning future use of CAD-CAM systems in the concrete construction
industry. The aim is to propose concepts for future use of CAD-CAM systems and
scenario's for the establishment of these concepts. Emphasis is put strongly
on the practical value of CAD-CAM systems in the concrete construction
industry.
     Five main steps can be distinguished in this study project (Fig. 5):
1. evaluation of the present use of CAD-CAM systems in the concrete
   construction industry
2. analysis of relevant trends and developments and their impact on the use
   of CAD-CAM systems
3. the development of future concepts and an impact-assessment-model
4. selection of future concepts with the impact-assessment-model
5. development of scenario's for selected concepts.
     This paper will present results of some of these steps for the use of
CAD systems for reinforced concrete detailing. Firstly, a description of the
subprocess 'reinforced concrete detailing' and a classification of CAD systems

are presented. Secondly the results are presented of surveys, performed in the Netherlands, concerning the use of CAD systems for reinforced concrete detailing. Finally an initial forecasting-model and a possible concept for reinforced concrete detailing, together with an example, are presented.

2. REINFORCED CONCRETE DETAILING

Reinforced concrete detailing is an important phase in the design of concrete structures (Fig. 1.), [2]. Other important phases are the preliminary design and global sizing & analysis. The first is an intuitive and creative proces, where computer-applications are hardly use. The second is dominated by calculations and hence the use of several analysis programs, such as FEM-programs, frame-programs, etc. For drafting CAD is occasionally used in this phase.

Reinforced concrete detailing involves several subprocesses, such as (Fig. 2.):
1. detailed sizing & analysis; calculation of the forces and the moments and the needed amount of reinforcement
2. design of the reinforcement; specification of the used type of reinforcement (diameter, length, shapes, quality, etc.)
3. drafting of concrete shapes and reinforcement
4. quantity take-outs and cost-estimate.

The design of concrete structures has interactions with projectmanagement, architectural design and installation-design. On the other hand, design is closely related to the production of the concrete structure. For reinforced concrete detailing both have significant influence, but the influence of the production is stronger, especially on the design of the reinforcement.
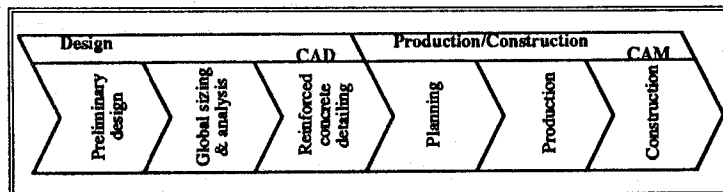
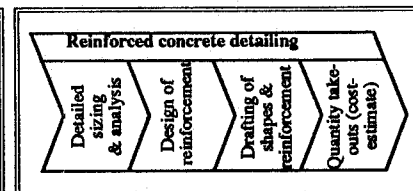Fig. 1. Design of concrete structures

Fig. 2. Reinforced concrete detailing

3. LEVEL OF CAD-SYSTEMS FOR REINFORCED CONCRETE DETAILING

The level of a CAD-system can be related to its functionality, which can be expressed in two ways. The first is the functions it can perform, e.g. the subprocesses it integrates. The more subprocesses are integrated, the more advanced the CAD-system should be. Advancement itself can be expressed in the amount of 'intelligence' that has been incorporated. For example, for the design of the reinforcement, 'intelligence' about the planning and production of reinforcement has to be incorporated.

The second is the level of integration in storage (and retrieval) of data-types in the CAD-database (Fig. 3.). Normally in the CAD-database only geometrical data is stored. Data about the quantity and quality (of reinforcement) can be incorporated in the CAD-database as attributes on geometrical entities. This non-geometrical data can be used for specification, quantity take-outs and cost-estimate.

Presently there are four levels of CAD-systems known in the Netherlands for the design of concrete structures (Fig. 4.). On level 1 are the standard CAD-systems, such as Autocad, Medusa, Intergraph, Cadam, Cadvance, etc., which supports drafting in general. They are used mainly for the drafting of the shapes of concrete structures and occasionally for the drafting of reinforcement. In this case almost always only geometrical information is stored.

Level 2 CAD-systems are an improvement of level 1, where additional routines and libraries have been added to improve the drafting-facilities for higher productivity. These systems are frequently used for drafting of the shapes of concrete and the reinforcement. At this level only geometrical data is stored in the CAD-database as well.

Level 3 CAD-systems are almost similar to level 2 CAD-systems. The main difference is that the CAD-database also includes non-geometrical, qualitative and quantitative data. These data enable the systems to perform some other functions, such as quantity take-outs, cost-estimates and production-planning.

Level 4 CAD-systems are expanded with modules for the design of the reinforcement in structural concrete members. In most cases the detailed sizing & analysis of the structural members is also integrated. These modules, which are mostly CAD-system-independent, exist presently only for beams with simple rectangular cross-sections, and for slabs, reinforced with standard (trade) nets of reinforcement. These modules could be developed due to the relatively easy to capture 'intelligence' for these elements to be incorporated in the module.
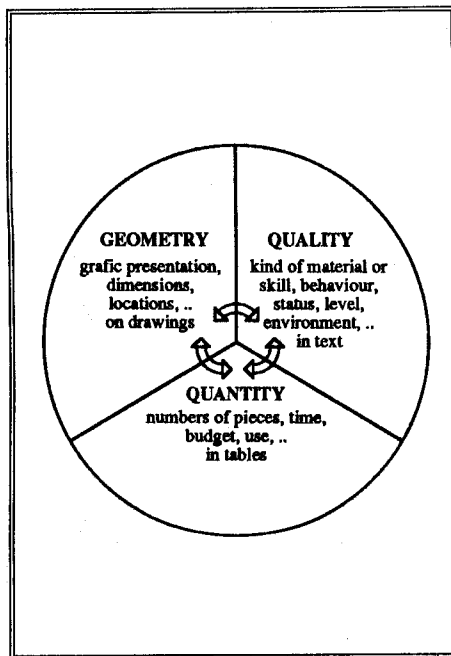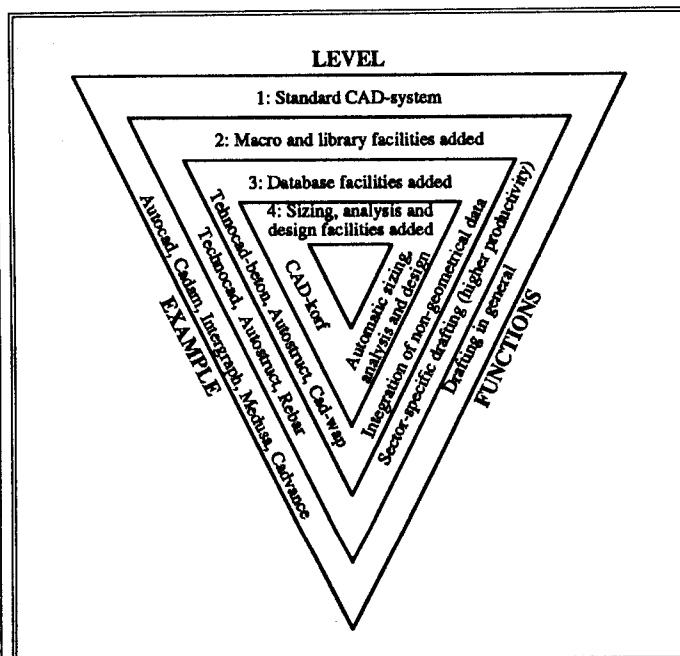

Fig. 3. Data-types

Fig. 4. Levels of CAD-systems

4. THE LEVEL OF DIFFUSION OF CAD-SYSTEMS FOR REINFORCED CONCRETE DETAILING (STAGES OF INNOVATION)

Besides the level of a CAD-system, there is also difference in the stage of innovation or the level of diffusion [3]. CAD-systems can be divided, on the basis of their adoption in the daily practice, in (adoption: percentages of the total amount of firms using a CAD-system):
1. conceptual systems
2. operating prototype of systems (adoption <5%)
3. introduced (initially operational) systems (adoption 5-30%)
4. average adopted systems (adoption 30-70%)
5. widespread adopted systems (adoption >70%)

A conceptual system is a description of a specific system as a solution to a certain problem. It is not a physical and functioning system and hence not adopted by the daily practice. The system has the potential to perform the desired functions or solve the problem of concern.

An operating prototype is a functioning version of a system, only adopted by firms involved in its development. It is a physical system that will only function satisfactory under the constant attention of skilled technicians. The system is still being tested and modified in this stage.

An introduced system has been tested well enough and is introduced on the market. The adoption is low due to high cost and inexperience with the system. In this stage the firms are exploring the facilities of the purchased system and modifications are made both by the developers and by the users.

An average adopted system has passed the stage of novice and constant modification and is well used by the daily practice. Only the cost of the system and the inexperience of the personnel with the system are barriers. By solving this problems and making the firms aware of the benefits of the system the adoption of the system can be increased.

A widespread adopted system is commonly used by the majority of the firms. The system is functioning well, only additional modifications are performed or extra functionality is added to the system. The cost of the system is in this case the most important bottleneck.

5. THE CURRENT STATE IN THE NETHERLANDS

Some surveys were performed concerning the current state of the CAD-use for reinforced concrete detailing in the Netherlands. One survey was an inquiry among the members of the ONRI (Society of Dutch Engineering Consultants) about the use of CAD. The aim of this inquiry was to determine the level of the CAD-systems used and their diffusion in practice. The group of about 64 engineering consultant-firms involved in this inquiry, was considered representative for the total Dutch engineering consultant-firms.

The results of the first inquiry are discussed in view of the several levels of CAD-systems. Results were divided in CAD-use for drafting of concrete shapes and for drafting of reinforcement. The results are first discussed in general; afterwards a division has been made, based on the number of technical employees, involved in the design of concrete structures, within the firm. Three groups were distinguished:
Group 1: less than 5 technical employees

Group 2: between 6 and 30 technical employees
Group 3: more than 31 technical employees.

Another survey was an inquiry among the larger engineering consultant-firms (group 3 of previous survey), which are more experienced with CAD or have the potential for the use of CAD for reinforced concrete detailing. The aim was to determine the constraints and the effects concerning the use of CAD. Project-managers, within these engineering consultant-firms were inquired; we thought that they could answer the inquiry the best. The results of this inquiry are also discussed for the several levels of CAD-systems.

5.1. Diffusion of CAD-systems in practice

The first conclusion, about the use of CAD for the drafting of concrete shapes (Table 1.), is that in general CAD is widespread adopted. However the adoption is significantly lower for firms in group 1. Further more, level 1 CAD-systems are widespread adopted, but are increasingly being modified to level 2 CAD-systems with more functionality. In particular in groups 2 and 3 this modifications have led to the widespread adoption of level 2 CAD-systems itself. In group 1 these modifications has not been done yet in the same magnitude. The modifications were mainly made to ensure the possibility for drafting of the reinforcement as well (Table 2.).

CONCRETE SHAPES	General	Group 1	Group 2	Group 3
level 1 CAD-systems	75	30	85	100
Level 2 CAD-systems	50	10	65	70

Table 1.   Percentages of firms using CAD-systems for drafting of concrete shapes.

REINFORCEMENT	General	Group 1	Group 2	Group 3
Level 1 CAD-systems	55	15	55	90
Level 2 CAD-systems	45	10	45	80
Level 3 CAD-systems	10	0	15	20

Table 2.   Percentages of firms using CAD-systems for drafting of reinforcement.

BEAM, SLABS (ST.NET)	General	Group 1	Group 2	Group 3
Level 4 CAD-systems	25	15	30	40

Table 3.   Percentages of firms using level 4 CAD-systems.

The adoption of CAD for drafting of the reinforcement is, except for the level 3 CAD-systems average (Table 2). However there is a variation from introduction for group 1 to widespread adoption for group 3. The level 3 CAD-

CAD-Systems	Level 3 and 4		Level 2	Level 1
	Block 1	Block 2		
Use of CAD is decided by	company-management	project-management	project-management	project-management
Characteristics of firm concerning the use of CAD	all facilities are present, very active in R&D	facilities present, active in R&D	experimental use, little R&D activity	experimental use, no R&D activity
Percentage of reinforcement-drawings made with CAD	almost 100%	between 0-100%, average 40-80%	between 0-80%, average 60-80%	between 0-60%, average 30-50%
Effect on the cost of reinforcement drawings (reduction: -)	variation between -0 & -40%, average about -20%	variation between +10 & -20, aver. less than -10%	unknown, estimated variation between +10 & -10%	unknown, estimated variation between +10 & 0%
Effect on the quality of the reinforcement drawing	positive on consistency, readability clearness, accuracy, storage	less positive than in in block 1	not very positive, sometimes no inprovement	arbitrary or low effect on quality
Effect on the duration of drafting (reduction: -)	variation between -10 & -30%, average about -20%	variation between -0 & -30%, average about -10%	variation between +10 & -10%,	variation between +10 & -10%,
Bottlenecks in the use of CAD	CAD-system, personnel,	CAD-system, personnel, high costs	CAD-system	CAD-system
Factors of stimulus on the use of CAD	'user-friendly' systems, links with production-planning and design	'user-friendly' systems, qualified personnel, links with production-planning and design	links with design	links with design

Table 4.   Some aspects of the use of CAD-systems for reinforced concrete detailing

systems are an exception; in general these systems are just introduced. These systems can be seen as prototypes for the firms in group 1. For the other 2 groups the systems are introduced by the major engineering consultant-firms.

Level 4 CAD-systems are in the introduction phase (Table 3.). There is little difference between the several groups; only in group 2 and 3 the adoption is average. The adoption is not high due to the high costs and the 'stand-alone' characteristics of the modules; the transfer of the complete data from the modules into CAD-systems still causes some problems.

5.2. Constraints and effects of CAD-systems for reinforced concrete detailing

There are several aspects, influencing the use of CAD for reinforced concrete detailing (Table 4.). It is obvious that the effects of the use of CAD depend highly on the level of the CAD-system. The higher level CAD-systems have better effects, but need higher investments in development and preparation for use of such systems. That is why they are only affordable by the major engineering consultant-firms.

Obvious is also that in all cases the possibilities of the CAD-system is not found adequately. The reason for this is the familiarity of firms with a certain level CAD-system. The possibilities of the system are known, but also the problems. The need for modifications and improvements are always present.

The need for integration of drafting with the design and production-planning of reinforcement is large. The possible benefits are recognized, but the integration is counteracted by the variety in concrete structures and in design of the reinforcement. Other problems are the segmentation in the building-process and the inadequate standardization and normalization.

Independent of the level of CAD-systems and the research and development on data-exchange [4], data is still transferred primarily by paper to other processes. Geometrical data (drawings) are increasingly exchanged in digital form, mostly in DXF-format. Non-geometrical data is often exchanged in ASCII-format or sometimes in DXF-format as a drawing (bill of quantities). Databases with geometrical and non-geometrical data are hardly exchanged, except in the case of fully compatible systems or within one system.

6. A FORECASTING-MODEL

Development in IT may not be the most important factor for its use in the concrete construction industry. This can be the conclusion on a comparison between the cuurent state of the use of IT and the possibilities of IT. There is a huge gap between the possibilities of IT and the application in practice. The gap is due to the specific characteristics of the concrete construction industry, which makes it inevitable to consider the use of IT in harmonization with these characteristics.

There are several methods to forecast the future use of IT in the concrete construction industry [5]; for all methods, however, it is essential to determine the most important influencing factors. This means emphasis is to be put on the factors determining the application of IT in practice, because it is the concrete construction industry which has to invest in the use of IT. This also means that the whole process of design and construction (and maybe even maintenance) has to be considered. Changes in one process can

have some important influence on the use of IT in another proces.

There are two main factors, which will influence the future use of IT in the concrete construction industry [6]:
1. future bottlenecks in the design and construction of concrete structures, which can be solved with the proper application of IT; for example, for the replacement or completion of construction resources, which are becoming scarce in the concrete construction industry
2. possible beneficial effects on the cost and quality of the building process and the final product (the concrete structure) of the application of IT.

The future use of IT has to be considered in relation with trends and developments in other aspects of the concrete construction industry. These aspects are country-, sector- and even firm-specific, due to differences in culture, tradition, environment, etc. They either influence the use of IT or create the environment for IT. Important aspects are (Fig. 5), [7]:
1. the organization of the building process
2. the building technology, with emphasis on industrialization
3. the qualitative and quantitative aspects of the building market
4. the possibilities of IT
5. the development in construction resources
6. the so called mega-trends with important (in-)direct consequences

At the DUT, within the CADCRETE-program an investigation has been started to study the future use of IT in the concrete construction industry in relation with these aspects. The study will analyse the impact of these aspects on development and use of IT in the building process. It will analyse the impact of future concepts of IT-use on the cost and quality of the process and product as well.
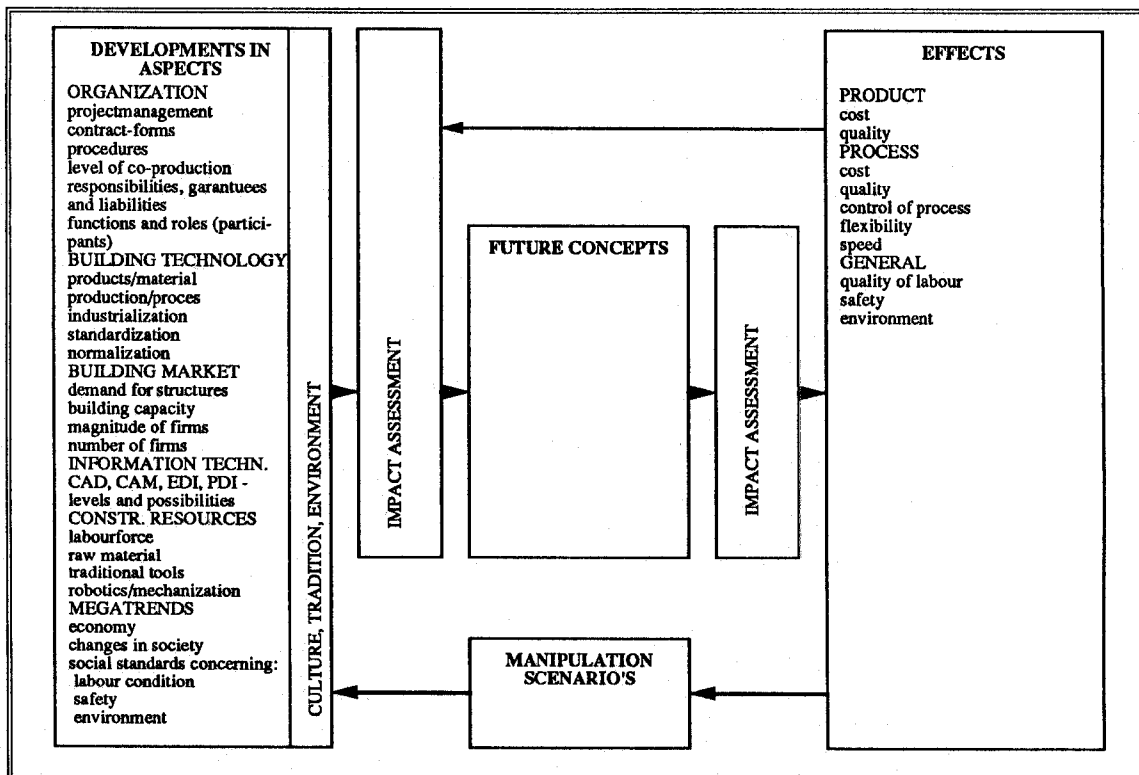

Fig. 5. A initial forecasting-model

7. A FUTURE-CONCEPT

A future-concept is presented here for reinforced concrete detailing of concrete buildings (Fig. 6C.), together with the present concepts (Fig. 6A&B.). In the future concept it is assumed that the greater part of the concrete structure consist of the structural members beam, slabs, columns and wall-segments. For these members CAD-independent modules have to be developed for the detailed sizing & analysis and the design of the reinforcement. Also a format has to be developed to transfer all geometrical and non-geometrical data from this modules into an interactive CAD-system for modifications and completion.
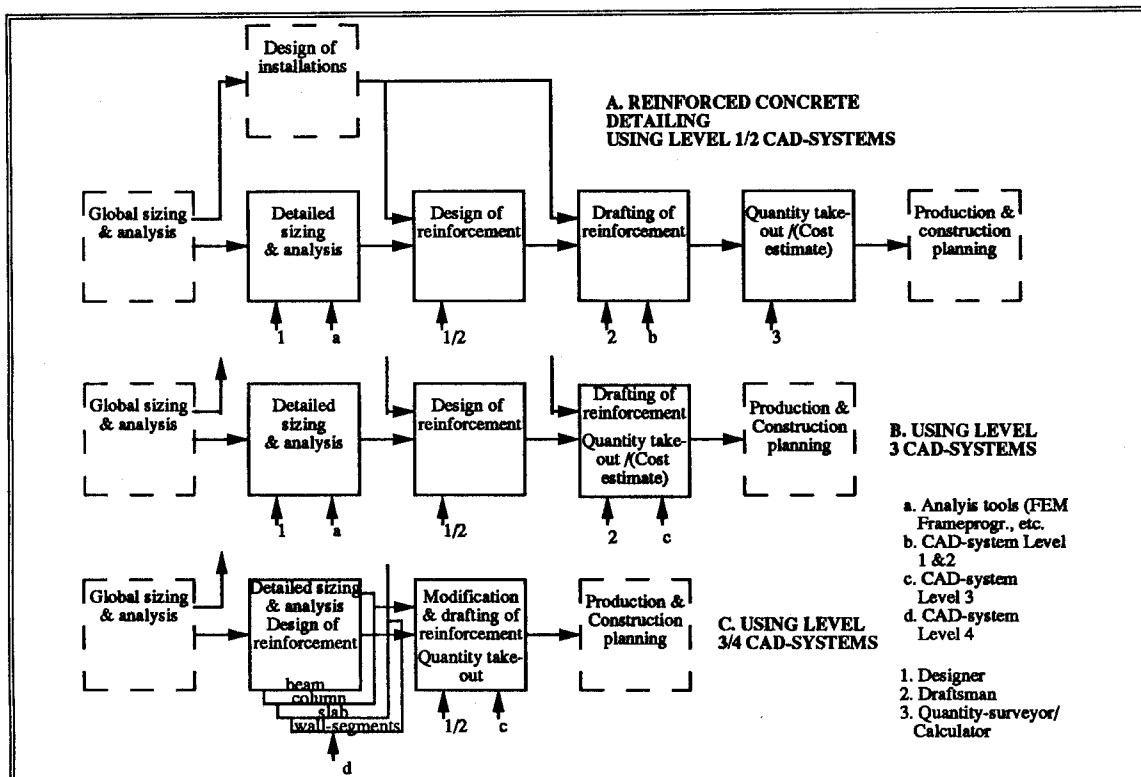

Fig. 6. Concepts for reinforced concrete detailing

The influence of planning and production on the design of reinforcement is important for this modules, as mentioned earlier. It determine the 'intelligence', to be put in the modules to get the appropriate information and data. There are some assumptions, regarding the future of planning and production of reinforcement, incorporated in the future-concept:
1. elements of reinforcement, such as cages, nets, etc., will be used instead of assembled reinforcement out of (bent) bars on site
2. elements of reinforcementare made automatically by CNC-machines
3. data for planning and production are exchanged in digital form
4. elements of reinforcement, with their connecting and end reinforcement are standardized

At this moment an operating prototype of a module for a beam has been realized in the CADKORF-project [8]. At one of the participants an interface

for a complete data-exchange between the module and their CAD-system is being made. For the other structural members research has been done for such modules in the CADCRETE-program. This has resulted in some preliminary conceptual modules.

It may be clear from the facts on the current practice, highlighted in this paper (and [2]) that practice is not only governed by IT-opportunities, but mainly by organizational practice, culture and tradition. Research emphasis on means of communication, as practiced in ISO-STEP-developments for instance, will not lead to integral improvements in quality and costs. Only development based on a vision on an integrated future comcept of IT in processes and communication will present a proper foundation for research and development for the future.

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