CADCRETE; Experience and future prospects of intelligent CAD-systems, automated reinforcement design and production and robotics in concrete construction.

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SUMMARY
This paper deals with some examples of an integrated use of computers in construction showing the weak and strong points of such developments. As far as reinforcement is concerned the examples include design and transfer of reinforcement data as product data interchange (PDI) and full automated production of reinforcement. The examples do further include a teaching program at Delft University of Technology checking students structural concrete design, a relative simple robot for drilling holes in concrete for fixing rails in concrete tunnels and an expert system for automated design of construction pits.
It is shown, that codes, the presence of a clear scenario for the extend of the use of an automated step in an early development stage and the sensitivity of a product or process for changes are of major importance for success.

1. Introduction

Most emphasis in the use of Information Technology in construction has so far been in the field of structural analysis. Since the development of CAD systems on a PC platform during the late eighties, the development of CAD drafting did take off in the construction industry as well. Real integration of structural analysis, materialized models, drafting, construction planning and actual construction has been limited to minor tests, prototypes and just experiments.

Visiting conferences and observing research being performed at universities, a few phenomena of interest for the subject of this paper can be observed. Conferences on subjects related to Information Technology are mainly visited by people working in IT only and most of the contributors are working as researcher and teacher at universities. As an example the contributions to a IABSE Symposium on KBS in Bergamo are listed below in table 1. [2]

Institution	No	Discipline	No	Character	No
University	277	Information Techn.	20	Investigation	20
Research Inst.	6	IT + Struct. Eng.	12	Prototype	12
Industry + Univ.	4	Struct. Engineering. Constr. Management	5	Implemented System	5

Table 1 Contributions to a IABSE Symposium on KBS Bergamo March 1995

The same is true for conferences on structural engineering and other established disciplines running their own societies, magazines and conferences. Of course structural engineers talk and write a lot about numerical methods in their domain, but they are usually not interested in the process of the design and educational software in structural engineering, requiring interfaces to really different disciplines.

From the author's experience it is essential that for successful development and implementation of IT systems in practice more knowledge should be developed and exchanged. Both successful and failed projects should be analyzed on lessons to be learned for the future. This is not only interesting for potential users, but for researchers and developers as well.

A recent investigation in the UK showed that only 40% from the "output" of structural designers was computer generated. All the remaining was generated by pocket-calculators, word-processors and handwriting. This shows that the structural design process , which basically involves the selection of shape, sizes and material specification of a structure, including the details, is obviously a very informal, hard to formalize activity. This conclusion is especially true where a structural engineer is concerned with other disciplines in construction and with code-checking.

Six projects initiated, developed and partially implemented under the supervision of the author in which some integration of traditional jobs has been achieved by a new computer system are discussed in chapter 2. Although the projects are quite different from each other, their initiation, development and implementation show to have a lot in common, which is explained in chapter 3 and 4.

2. Brief description of the projects

2.1 CADCAGE

A project between three parties, a contractor, a structural consultant and a reinforcement factory, with participation of Delft University, encompasses a program which was developed for automatic calculation and generation of the reinforcement in a continuous beam of given sizes. The Dutch Concrete Code was used and an agreement was reached on the rationalization of the reinforcement in prefabricated cages and supplementary bars. [1]

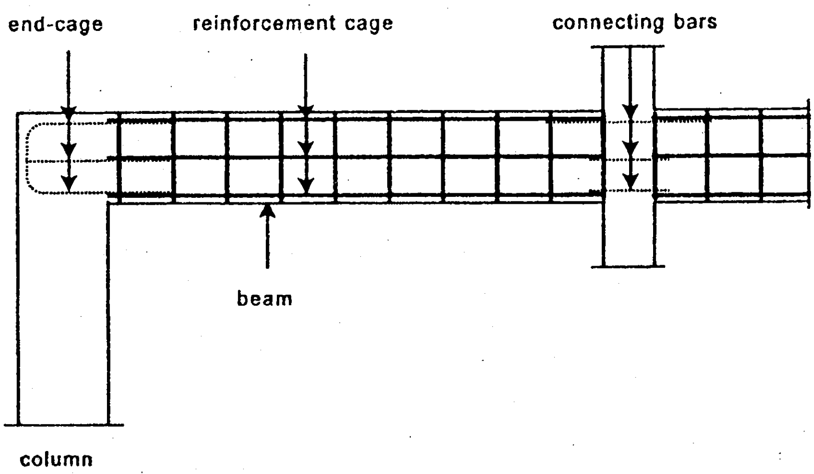

Fig. 1 *Sketch, showing the standard cage reinforcement for a continuous beam.*

2.2 CADFORM

A CAD program was developed within a contracting firm, having its own form work manufacturing shop, for the interactive design of formwork according a standard system (DOKA). Parts of the drawing were generated automatically, just like component lists, estimates and other logistic support data. The program was further used to steer a milling cutter machine for plate material for form work. [1]; [3]

2.3 CAD reinforced concrete exercise

A TU Delft CAD exercise for students is to size and detail a simple RC building consisting of continuous beams, slabs and columns. Students select concrete sizes and quantities, position cover and shape of the reinforcement. The program checks everything against the Dutch code. After sufficient rounds of comment and corrections, the computer provides bills of materials and costs. An extension of the program with a parameter study is under development, as well as a version under EC2. [2]; [5]

2.4 "WUF" (Wapenings Uitwisselings Formaat) Reinforcement Exchange Format

A PDI format, "WUF", for the exchange of reinforcement data between the CAD program of the structural engineers and the logistic programs including NC functions of the reinforcement manufacturer was developed and implemented on the Dutch market. Two contractors, two structural consultants and two reinforcement factories ran the project, with assistance from Delft University. The project involved process studies, rationalization and standardization as well. [6]

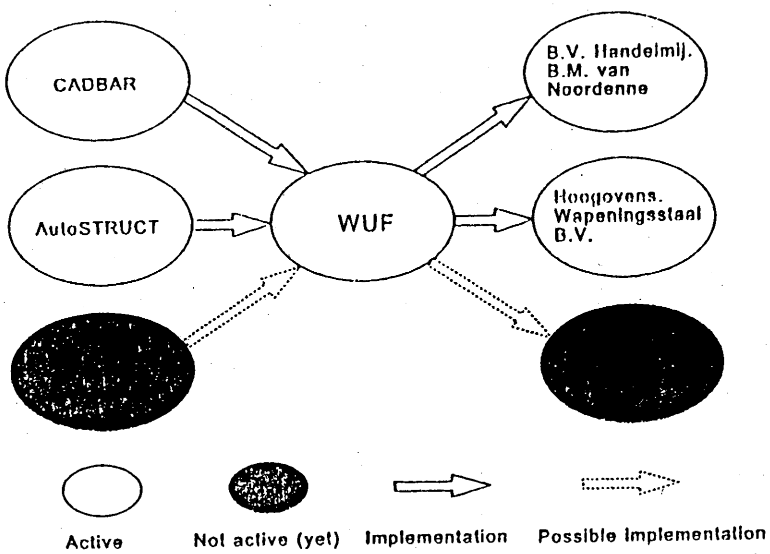

Fig. 2 Diagram showing the PDI format "WUF" for reinforcement data

2.5 Walking Drill (Loopboor)

A Robot project was initiated for the development and implementation of an advanced Robot for drilling holes to attach rails on RC concrete structures, within accurate geometry and avoiding drilling through reinforcement. The robot was developed by two contractors, a manufacturer of drills and the Dutch Research Institute TNO. [4]

2.6 Construction Pit**

A program for the automatic design of construction pits of different concepts (0, 1 or more strut layers, different construction sequences, etc.), with sheet piles, strut frames and standard details is developed and implemented by a contractor.[7]

3. Differences and conformities of the projects

As can be observed from table 2, the projects had one or more participants financially contributing and working in the development. Apart from that, research students were used mainly to perform formal process analysis of the projects. Although some projects were worked on by only one party, different departments and skills were still involved. CADFORM used designers, estimators and the manufacturing unit, the CAD exercise involved the regular staff from the structural concrete section and the University-CAD training center and PIT Design involved the design office and the planning and estimating department. This observation of multi-partner involvement is quite essential as it requires special attention to motivate different people to participate in a project and stating a commitment for implementation. This in turn requires some teaching and analysis of the effects of the system on the product and the process to ensure dedication to the system under development.

A well known diagram, see fig 4, showing the relations between new technology, people, organization and product, becomes apparent from the first moment onwards.

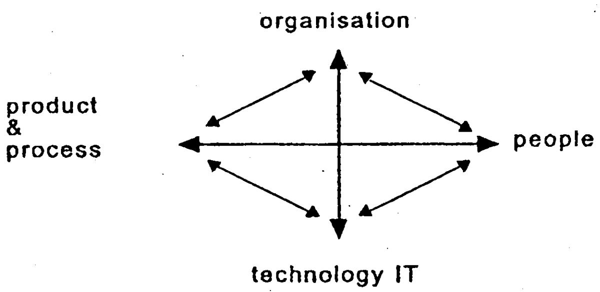

Fig. 4 Diagram showing relations for implementing new technologies.

All projects had a substantial size that required careful planning and explicit dedication of budgets. The figure 1,0 for relative costs in table 2 corresponds with a budget required for about 6 man years. Substantial hardware is included in the figures for the Walking Drill and CADFORM. Cost overruns vary from virtually none with 3 of the projects to substantial figures for the other 3. Chapter 3 explains why.

Four projects were anticipated by the production of a prototype. In case of CADFORM, prototyping was in fact closely approached by testing system modules step by step after which it was decided to incorporate a certain module in the final system. The Robot project, Loopboor, was in fact selected in such a way that only well known techniques were used and assembled in the system in order to reduce the chance of failure.

Prototyping still involved quite an amount of time where different partners were involved, because finding a real project with the involvement of these partners was difficult.
Only one project failed in actually being realized for reasons as explained in chapter 4. The others are in use, two of them already more than 5 years.

	Partici-pants	Relative costs	Cost overrun %	Time prototype	Time production	Project start	Production start	Use standard
ηge	3	1,0	<10	18	--	'88	--	--
orm	1	0,4	<10	--	12	--	'87	'88
xercise	1	0,4	30	18	12	'88	'89	'90
	6	0,6	<10	36	12	'91	'94	'95
ing Drill	4	1,0	30	--	30	'91	'92	'94
sign++	1	1,1	40	6	20	'93	'94	'96

le 2 Development data from the systems

Strategies used for initiation, development and implementation of the projects

e management of construction firms is asked for the reasons as to why new Information nology Systems should be implemented, the answer will be close to "improvement of ty and effectiveness". [8] Asked for the kind of systems they prefer most, many answers ate a preference for systems that support knowledge management in one way or another, st certainly involving KBS, Intelligent CAD and 3-D CAD.

six systems discussed were "sold" under different qualifications as illustrated in Table 3. y out" motive was quite important to all of them, except CADFORM, for in that case gh examples from other industries were sufficiently convincing. The "try out" concept mportant, both at the stage where a prototype was developed as well as at the initiation development of the final product.

bvious that the improvement of labor conditions was an important issue for constructing ot, but it was also recognized that in the case of automatic Pit Design sound and proven ing could be incorporated, contributing to health and safety during construction.
l was of course an obvious element in selling all of the projects to the contributors, t for the CAD Exercise. In that case speed for the university staff in correcting student ns was obvious, but whether, in time, the load for the students would more or less igh the same or an improved learning effect was unclear.

Selling "efficiency" for the projects was avoided in some cases, as this would immediately raise the questions: "How much?" and "For whom?", which is not a good starting point for a joint development project. In cases where such a question came up, the answer was that the project would lead to an integral cost-saving for the benefit of the client. Such figures were consequently supported.

In the end improved quality acted as a general point of attraction for all of the projects. More accuracy, less errors, more appropriate for use, improved rationalization and forced use of proven experience were some of the points that effectively addressed quality considerations. It must be said that as far as the projects are in use at present, these "selling points" have proven to be valid.

	Speed	Efficiency	Labour conditions	Quality	Try out
Cadcage	+				+
Cadform	+	+		+	
Cad exercise				+	+
WUF	+			+	+
Walking Drill	+	+	+	+	+
Pit Design++	+	+	+	+	+

Table 3 Main reasons for development of the systems

Observing some characteristics of the six projects, some of them obviously proved to be more important than others. This is shown in Table 4.

Process and product required a clear definition of where automation starts and where it ends. This was more or less neglected in the case of CADCAGE, which also contributed to its follow up as a production system. The pressure of IT specialists is usually high for extending the scope of systems under development. The choice in Pit-Design to start with a selected concept was very much against the wish of KBS fans to include the choice of a concept. In practice, never more than two concepts are feasible in any case, which means that both these concepts can be elaborated on by the program, optimized and estimated, giving a fully evaluated choice between the concepts. Staying with the Pit-Design it is worth mentioning that is was decided to stop the system after selection of sheet piles, frame and type of connecting details including the design report required for certification. From that point onwards, the model is passed to a conventional CAD system for further unique detailing as given by site conditions.

Another rather important subject is the initial idea of a scenario of how the system was going to be used between the different parties on a segmented job. This effects the organization after implementation and may change tasks and responsibilities. For that reason the site management of the job where the Walking-Drill was going to be employed first, was engaged in the development, as drilling holes changed from a subcontracted job to a main-contractor work. For CAD-Form tasks between design, planning and manufacturing changed as work on detailed geometry moved from manufacturing to design. The CAD-exercise required new instructions and another type of supervision and abandoned correction by staff. Sometimes, as was the case for the PDI format WUF, the system had to be sufficiently flexible to allow for more scenario's or process-organizations.
The initial development of a prototype proved to be very helpful for adjustments of the scenario before final programming started. A prototype is also useful to obtain an impression of the budget required for a production program worth developing. This means, however, that the real world for a production program can be compared with the selection used in the prototype and evaluated in efforts required for programming. Such techniques are not very well known and usually neglected by developers of prototypes.

	Scenario for use	Start	Finish	Demo first	PDI aspects	Code sensitive	Code changed	Product changed	In use
Cadcage	–	–	–	–	+	+	+	–	–
Cadform	+	+	+	–	–	–	–	+	+
Cad exercise	+	+	+	+	–	+	+	+	+
WUF	±	±	±	+	+	+	–	–	+
Walking Drill	+	+	+	–	+	–	–	–	+
Pit Design++	+	+	+	+	+	+	+	–	+

Table 4 System characteristics of importance for development

A primary source of disturbance were changes in codes during development and after deployment. This formed the main reason for delays in the CAD-exercise and Pit-Design and became even prohibitive for the continuation of CADCAGE. Developers of codes should note this and try to make codes in such a way that changes will only effect numerical values of coefficients that can be handled as default values. The Eurocodes under development have a great potential for the development of code sensitive software in case the rule above, realized by a system of "box-values", is really effectuated.
Changes in the product during development and use are very significant to ultimate success or

failure. For WUF, focusing on conventional reinforcement, the walking-drill focusing on holes in concrete plates to attach rails, and Pit-Design focusing on construction pits consisting of standard sheet-piles and steel beams, the market seemed sufficiently continuous to develop the program. The same was true for CAD-Form, but after some years of use, when the standard detailing with the DOKA system was abandoned, the program lost functionality. This proves that for the design and production of certain rapidly changing products, automatic procedures will be extremely difficult.

5 General conclusions for future IT projects

As was demonstrated by the evaluation of the foregoing examples, success of an advanced integrated IT project is very much a question of good communication and consequential understanding.

A last example will show this. In southern Germany an experiment was worked out and implemented with fully integrated analysis, reinforcement design, manufacturing and placing of reinforcement in a flat slab. What in fact happened was the application of a finite element analysis on a flat slab which was able to transfer the internal forces in the slab into a pattern of reinforcement. This reinforcement did exist out of two mashes of common reinforcement bars into one direction and hoopsteel spot-welded against it in the other direction. The digital model of this reinforcement is loaded into a machine which produces automatically the required mesh, rolled into a unit that can be transported to the site. On site the rolled meshes are unrolled perpendicular to each other providing the required reinforcement in the slab.

The advantages of the system are clear. A gain of steel in the order of 30% is claimed to be possible as reinforcement bars can be of different individual length each as long as the hoopsteel has the full length of the slab. Speed of the whole procedure is of course an other advantage as well, just as avoiding difficult and heavy work, the avoidance of errors and a better quality of the whole product.

The problem however to develop and introduce such a system is the joint effort of many parties that have to believe in the success. It is a software developer, a consultant to use that software, a machine factory with design capability for special equipment, a reinforcement factory, a steel fixing firm, a main contractor, a steel supplier, a client interested in experiments and a willing certification authority. Nine institutions all together, with all of them having there own interest in such a project. Some of them gaining, some of them losing, turn over in case of success.

This example shows very good that fresh ideas on integrated IT projects should be handled with care and a clear view on factors that influence success and failure.

Such factors for success are: a clear picture of where automation should start and where it should stop, a scenario of how the system should be used in the organization in relation to the existing process, a realistic idea on the consequences of likely changes in codes that will influence the validity of the program and last but not least an evaluation of the consequences of likely changes in the product itself.

More work is required on the development of models that may predict the difference in effort and costs in-between the development of a prototype and a full production system. Honest exchange of experiences of successful projects and of failures in conferences, including industry and the academic world are required. The academic world should consequentially raise more interest for the problem of development and implementation of systems.

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