AUTOMATION AND LOGISTICS
IN PRECAST CONCRETE
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AUTOMATION AND LOGISTICS
IN PRECAST CONCRETE

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INTRODUCTION

In October 1990 the Delft Precast Concrete Institute (DPCI) organized its first symposium, entitled "Prefabrication of concrete structures". During this symposium a state-of-the-art was presented, dealing with well-experienced concepts and solutions for the design and the construction of prefabricated concrete structures. One of the things the symposium learned is that an essential part of prefabrication is the organisation. This concerns not only the organisation of the cooperation between the architect, the designing engineer, the producer and the contractor, but also the organization of the production plant, the design office, the transport and the assemblage.

In order to maintain its prominent place, the prefabrication industry has to take full profit of the development of new tools, such as CAD/CAM programs and modern means of communication. If used well, the use of CAD/CAM programs will result in a decrease of the time needed for design, calculation and detailing, a reduction of the costs and an increase of the quality. CAD/CAM programs are, however, not readily available and have to be developed making adequate use of the firm's experience and its idea of the future development. Therefore no standard products are achievable, but a variety of solutions is observed.

Special attention has also to be paid to the organization of the production process, the stocking of the elements, the transport and the assemblage at the building site. Especially the interaction between these processes should be given due consideration. An important point to be taken into account is that there is, nowadays a clear tendency to use larger and larger elements. Large dimensions do not only offer the advantage of large spans, but also a minimum number of connections and associated assembling actions. The consequence of larger dimensions is, however, that the production-, transport- and assembling procedures must be more accurately planned and coordinated in order to prevent inefficiency.

In this symposium a number of experienced people present their ideas on automation and logistics in precast concrete. The fact that they do not only work in different stages of the prefabrication process, but also come from different parts of Europe, guarantees an interesting confrontation of approaches. We hope that the presentation and the discussions will lead to a better insight and an increased creativity in finding new methods to improve and further develop the prefabrication process.

The editors
SESSION 1

CONCEPTS/DESIGN AND CALCULATIONS/REINFORCEMENT
Automation from design to execution; an example from the practice

J.J.M. Font Freide
1. INTRODUCTION

The first goal for automation has to be saving costs. In many cases in the prefab concrete industry is this possible by automation of the rather complex process before the elements are actually produced. Automation of the design, the structural calculations, drawings logistics and administration.

Manufacturers who are able to do a rather big investment at once, can give an order to a software developer to develop the complete software which is necessary to automatize the complete process of design and logistics. Than they can start at a certain moment with the new, automatized, working process. The high investments done, has to be gained back during the future. Not all manufacturers are able to do these high investments. Besides this, this way of automation has also the risks that the new automatized process does not work perfect in the beginning or that the working method, which had to be choosen before the development of the software, is not completely satisfying.

Because of these reasons our office developed in cooperation with a manufacturer of prefabricated one family houses, software which could be developed step by step, within an overall structure, so that immediately after finishing each step, this part of the programme can be operational and earn money to do the next step. We developed the programme first to do the structural job, but in such a way that the programme can be extended to other disciplines.

2. THE PREFABRICATED ONE FAMILY HOUSES

The system for the houses was developed about 20 years ago by Elementum, a prefab industry in the Netherlands. The one family houses are basically the same, but vary in detail rather much.
Because of this variation it is not possible to standardize the elements with which the houses are build. For every type of dwelling, for every project, it is necessary to make shopdrawings for all the elements and to make the structural calculation to determine the amount of reinforcement. Also the cast in items, such as electrical plugs, connection and mounting items and so on, have to be on shopdrawings.

The houses are build with large prefabricated concrete elements. The wall elements have a maximum length of 9 m and a height of 2.5 m. The hollow core floorslabs have a width of 3 m and a length of maximum 6 m. The lateral stability is provided by concrete shearwalls located besides the stair.

Mostly the walls at the upper floors have sloping edges. The cast in items are electrical provisions such as plugs, pipes etc, but also the materials which are necessary for the erection and connections such as welding plates, starter bars, lifting anchors and inserts. All these things are standardized but the location and the number is always different. Also the windowopenings are varying.
The reinforcement in the elements could be standardized but it's more economical to calculate the amount of reinforcement for each type of house separately. So, each element is basically standard, but the dimensions vary. The cast in items are standard but the location and number vary.

3. AUTOMATION OF THE DRAWINGS

It is to make drawings by means of a CAD programme such as autocad, cadvance etc. These software are grafical. The drawing is made by drawing lines, circles, squares etc on the screen. The computer knows this drawing as drawing, not as a product. We choose an other way for this programme. The input is not based on drawing items but on the data for the product. The drawings are automatically generated. For instance, is the length of a wall element known, the computer can make a drawing of the boundary of the element for the height of the wall is standardized.

This way of working is also done for the drawings of the cast in items. For instance, for a lifting anchor, stirrups included, only the pressure from the edge should be given. The little drawing for this anchor is programmed. Besides this the computer knows that this drawing is a lifting anchor and is able to count and print the number of anchors used.

Fig. 1. lifting anchor
4. PRINCIPLE TO THE PROGRAMME
After the choice was made that the drawings should be generated from the input of only the varying data, it was obvious to base the total automation system on what could be called "product input"
This has large advantages. The input data are data concerning the house itself. The computer knows the houses as houses. The separate elements and cast in items included. These data can be used for other purposes than making a drawing only, so also for calculations, logistics and administration.

The programme is build around a central datafile, in which the data for the house is stored. (fig. 2)

Fig. 2. Structure of the programme.
5. INPUT MODULE
With the input module the user can give the relevant information for the type of house concerned by menus. A simplification which saves a lot of input and inputtime is that as a start, the programme reads a standardized house-file. In this file, all data for the most usual type of house are stored. The programme is based on changing and editing this most usual data. So for a type of house which only little deviate from the most usual type, only few additional input is necessary. After the programme was made it turned out that these simple, partly standardized houses were determined by 700 to 1000 figures. All these figures can vary so the number of different types of houses can be tremendous.

6. CALCULATION MODULE
Per type of house only the calculations which are necessary to determine the reinforcement in the elements are made. These are the calculation of the lateral stability, the calculation of the floorslab and the calculation of the wall elements. The loads are generated from data in the house-file. For instance, the windload is determined from the dimensions of the cross section of the building, stored in the datafile. The calculations are simplified as much as possible. Complicated calculations were made seperately and resulted in simplified checks which can be made by computer in a quick way, without the need of complicated software (for instance for the connections). The calculation of the stability restults in forces acting on the floorslabs. Theses forces are stored in the datafile and used for the calculation, for the floorslabs. The calculation of the floorslab results among others, in loads on the walls.
These loads are also stored in the datafile and used for the calculation of the wall elements at any time the user chooses. By generating the loads form the realistic data in the datafile for the house itself, almost no additional input for the calculations is necessary. The calculation programme uses the same data as the other programme modules.

The realistic results of the calculations, for instance the amount of reinforcement, are also stored in datafile and can be used for making the reinforcement drawings, but also for ordering the reinforcement and so on.

7. DRAWING MODULE.
This module is used to make the detailed shopdrawing for each element. These shopdrawings are used for the preparation of the production for the building of the moulds and for the production itself.

Cast in items have a code. The computer knows how much items for each code are needed for each element and for each project (stored in the central datafile).

Fig. 3., example of a drawing of a floorslab with recess for a stair.
In the central datafile is the data for the house as a complete unit stored. The computer splits up the house in elements according to certain rules and determines which items have to be in the several elements. So the input can be done for the house as a total. It is for the user of no concern which item in cast is in which element. For instance an electrical pipe is put in as a pipe from groundfloor to second floor.

The computer knows that the pipe and the necessary connection items have to be cast in in three wall elements. A connection is determined by the location of the connection. The necessary input is one figure. The computer knows that a certain connection needs certain cast in items in several elements.

The floorslabs are determined by the type of house concerned. All the data necessary to calculate and draw the floorslabs are available in the house-datafile concerned.

The wall elements can be determined by more than one type of house. So in the input module also a datafile for the situation of the houses is made. (This file is also necessary to determine the amount of materials which is needed for the total project.)
8. EARNING CAPACITY

By using the programme only for the structural calculations and the shopdrawings, the total costs for these activities taking into account the costs for the development of the programme, were reduced by 50%. The programme was developed step by step. First the drawing module, then the overall input module, and so on. Each part was operational at once, so the development of the next module could be financed with the saving the former module made possible.
9. FURTHER DEVELOPMENTS

Due to circumstances the production of this building system for one family houses stopped, and the development proces for the programme had to be aborted. It’s possible to develop these kind of programmes with these kind of structures to a complete automation system for design, calculation, drawings, logistics, ordering materials, purchasing and computer aided manufacturing.

Fig. 5. Scheme of the building proces.

Choosing for the "product input" instead of using the standard CAD software, makes it possible to make a programme which is able to cover more than one discipline in the building proces. Doing this makes it possible that a discipline uses the input which was given by the former discipline.

The part of the building proces which is covered by the programme can be extended to the left (architect) and to the right in the scheme of fig. 7 (manufactory) step by step, while the costs and the methode of automation remain under control.
In this section, the authors discuss the importance of ongoing research and development in the field of education. They emphasize the need for innovative approaches to enhance the effectiveness of educational programs and prepare students for the future challenges of the global economy.

The diagram illustrates the various components of an educational model, highlighting the interconnectedness of different aspects such as curriculum development, technology integration, and student engagement. Each component is represented by a box, and arrows indicate the flow of information and the exchange of ideas among these elements.

The authors conclude by stressing the significance of collaboration between educators, policymakers, and industry partners in shaping the future of education and ensuring that students are equipped with the skills necessary for success in an ever-evolving world.
Automation in the design and production phases of the Storebælt bridge

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Automation in the design and production phases of the Storebælt bridge.

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Summary
Computer Aided Design has proven to be a valuable tool in the design process of the Storebælt West Bridge. Large time gains have been achieved by using CAD in the different engineering disciplines. It needs no argument that electronic data exchange will be used more frequently in the building practice. Here, the electronic drawing will play an important role. In this respect, the Storebælt project can be considered as an example project. Standardization of the creation methods of CAD drawings is very important, as is the managing and controlling of CAD data and the processing of it.

Mr. de Jonge graduated in 1989 at the Eindhoven University of technology in Building Engineering and is working for Ballast Nedam Engineering since 1989. He has supported the applications in the field of Computer Aided Design in the Storebælt West Bridge project.
1. INTRODUCTION
The Storebælt West Bridge is a 6.6 kilometre long concrete structure, designed to carry rail and road traffic across the Western Channel of the Storebælt in Denmark, linking Knudshoven on the island of Funen with the little island of Sprogø. From here, across the Eastern Channel to the island of Zealand, on which Copenhagen is situated, the fixed link across the Storebælt will continue in the form of a bored railway tunnel and a second bridge—the East Bridge—for road vehicles. Bridges and tunnel will connect the Danish islands to the main road and rail networks of Europe. When fully completed in 1997, the Storebælt link (see figure 1) is expected to double the number of car crossings and to triple rail transport.

The West Bridge was designed at the office of Ballast Nedam, the leading member of the European Storebælt Group (ESG). The design centres on the use of large-scale, pre-fabricated concrete elements. ESG won the contract to construct the West Bridge as a result of an alternative design and less expensive design proposal. Originally three girders per span were specified, one for the railway lines and two for the four lane motorway. In the alternative design the two motorway girders were combined to one, and the girders were given an arched shape, which not only made the bridge look more attractive, but also resulted in a reduction of material costs.

2. PROJECT OVERVIEW
2.1 Composition
The West Bridge comprises 63 spans and has a free height (navigation clearance) of 18 meters at the centre. In effect there are two separate but parallel bridges, one for road traffic and one for rail traffic. The girders are both supported, through pier shafts, on piers or caissons (see figure 2).

2.2 Prefabrication
The elements of the structure, caissons, pier shafts and girders are fabricated in a pre-fabricating yard (in Nyborg) and then transported to their final destination in the Western channel using the floating crane Svanen, specially designed for
this project. In total 62 caissons, 124 pier shafts, 62 railway girders and 62
roadway girders are required. In a 30 hectare prefab yard the elements are cast
on five production lines, using purpose built lifting equipment and a large
number of tower cranes.

Figure 2. Visualization of Storebælt project

2.3 Elements
The caissons are the shared foundation of the West Bridge for the road and
railway girders. The caissons, consisting of a base slab, walls and a plinth, vary in
height from 7 to 28 meters and in weight from 4,000 to 7,000 tonnes, depending
on their position in the alignment. The bridge elements, both supported by a
separate piershaft, are 110 meters long. Those for road traffic weigh 5,800 tonnes
and are 23 metres wide. The railway girders weigh 4,800 tonnes and are 11.5
meters wide. The girders are connected to each other to form continuous, joint-
less bridge sections of 1,100 meters in length. Six sections make up the total
length of the bridge (6,600 meters).

2.4 Offshore
Prior to placing the 62 caissons, the seabed has to be prepared. This is done in
several stages: first it is necessary to excavate down to a firm bottom at each
caisson position; then a self-elevating platform, Ballast Nedam’s ‘Buzzard’,
places, compacts and levels a 1.5 to 3.5 metre thick crushed stone layer, to a
tolerance of 5 cm. When the foundation bed has been prepared and the concrete elements made ready, Svanen picks up the elements from the prefab yard and transports them to their 'exact' (maximum tolerance of 2 cm) location in the Western Channel.

3. ORGANIZATION OF INFORMATION

3.1 Information system

All documents which are created during the design process, are stored in the SBF (StoreBæltForbindelsens) database. In this database a distinction is made between: drawings; technical information, other than drawings; administrative information and information regarding project planning and costs. During the project the database acts as an electronic reference, which is an aid for SFB to control and judge the progress of the project. All parties involved in the building process have access to the database.

In practice the database is mainly used for extracting CAD-drawing files. The Danish railways (DSB), for example, uses the CAD files produced by ESG as an underlay for creating their own drawings. The CAD workstations located on the pre-fabrication yard in Nyborg are also connected to the central SBF database. In Nyborg the so-called 'as-built' revisions are created.

The digital transfer of a CAD file is accompanied by an A2 size paper copy, provided with the necessary signatures, which is the only legal document. To be sure the digital data transfer will be meaningful, SBF has prescribed which software has to be used in the different application areas. For planning the Artemis software has to be used, for text processing the WordPerfect software, and for CAD a choice could be made between Intergraph or AutoCAD.

After the completion of the project, the information will be stored in an operating and maintenance system. This system will be based on a three dimensional (3D) CAD-model of the bridge. One of the functions of the system will be the possibility to point to parts of the structure, and automatically create lists with digital documents regarding this part, which can be viewed or plotted.

3.2 The use of AutoCAD

For the West Bridge a total of about 3,500 drawings have been made with the AutoCAD software. In terms of data storage about 2 Gigabyte of graphical information had to be stored. During the design about 400 Megabyte had to be accessible simultaneously from the central database. This amount of data asks for a solid organisation of production methods and document control. Both the production methods and the methods to control the flow of the documents have been described in a CAD-Manual, which is part of the Quality plan in the project.
3.3 Production of drawings

One of the most beneficial properties of the use of CAD is the possibility to coordinate information between different disciplines. To fully exploit these possibilities, arrangements had to be made about the CAD-database structure. At file level the layer coding system is important, at database level the distinction between file types (see figure 3). In the CAD-database three file types exist: standard data files; model files (3D and 2D); and drawing files (2D).

Standard data consists of symbol libraries, but also data from other software, for example geotechnical information from an external database. Drawing files are composed from standard data files and model files. The essential distinction between model files and data files is that drawing files have scale dependent information (such as text and dimensions), which model files don’t have. The drawing file is the electronic equivalent of the hand made drawing on a drawing board. The model file represents the building on 1 to 1 scale. Through automated procedures alpha-numerical reports can be created from these 1 to 1 scale model files. The final documents (plots) are created by combining the drawing files with alpha-numerical data from the document control system.

3.4 Layer coding system

For the Storebælt project a layer coding system has been used, that has been developed inside the Ballast Nedam organization. In this system the layername consists of four characters. The first character stands for the building discipline, the second for the sub-discipline, the third for a division and the fourth character for the line thickness. The layercode '3482' for example, stands for graphical entities which are text (division 8), have to be plotted with a penwidth of 0.25 mm (line thickness 2) and refer to the reinforcement (subdiscipline 4) of the structural discipline (3). The layer structure is the key to sophisticated use of AutoCAD. A simple and comprehensive layer naming scheme supports: the co-ordination of disciplines, range selection of layers, uniformity in layer naming to perform automated scheduling and is the interface to other CAD systems.

Layercodes are also used for object recognition, through which it is possible to automatically generate reports. Examples of these applications will be shown further on.
4. AUTOMATION APPLIED IN DESIGN

4.1 Alternative design and Geological investigation

In the starting phase of the project, CAD has been used to build a global 3D model of the alternative design of the bridge. The model has been useful for calculating concrete volumes and presenting the alternative design. The 3D model also assisted in the research of the complex spatial shape of the hammerhead walls in the road and railway girder. Information regarding geological information was also brought into the model. Together with other geological information, excavation drawings have been generated automatically (see figure 4). These drawings helped to increase the accuracy of placing the caissons.

4.2 Posttensioning cables

The road and railway girders in the project are prestressed by using the posttensioning method. The position of these posttensioning cables (tendons) inside the structure vary in every cross section. At the start of the design process the path of the tendons is sketched as a starting-point. In the final calculations and drawings the path of the tendons must be exact. Here a number of qualifications have to be fulfilled: the tendons must fit inside the concrete shape, enough space must be left for the normal reinforcement, the minimum distance between the tendons must be obtained and the tendons must be able to manage the stresses. Based on two dimensional models this is a tedious job, which requires a good spatial understanding.

For the detailed engineering of the tendons in the West Bridge, we therefore used a 3D CAD model (see figure 5), which must be seen as a series of cross-sections, which are connected to each other by a number of wall planes. In this
3D model the tendons are drawn using project specific routines. On critical points the location of a tendon is entered based on information supplied by the engineer. After entering all critical locations the tendon is automatically drawn inside the concrete shape.

The CAD engineer then performs a visual check on the path of the tendons in respect of the concrete shape and the normal reinforcement. On critical locations, i.e. the diaphragm wall at the girder support, the normal reinforcement is entered in the 3D model to be able to check conflicts with the tendons.

After the visual check is carried out, an AutoCAD application is started to generate 2D cross sections. The result of this application is a fully automatically generated section and a table with the exact tendon location (see figure 6). This graphical and alpha numerical data is then used by an engineer for further calculations and optimalization of the posttensioning design.

Using this workmethod, it is possible to generate all cross sections for one girder (one at every metre = 55 cross sections) in only a few hours, and revision of the posttensioning design can be done in short time. Besides the time gain compared to working with 2D models, it is plausible that the number of errors is reduced enormously.

4.3 Reinforcement
The reinforcement drawings in the substructure of the West Bridge are prepared with AutoSTRUCT, a reinforcement detailing software application, which has been developed by Grabowsky & Poort. The software, running under AutoCAD, has been tested extensively at the start of the project. As a result of this, a number of changes and extensions have been made to the application. Additional routines for drawing hairpins and adaption to British and Danish standards, are examples of these modifications. These modifications led to a 'Civil module' in the software. An important option available in the AutoSTRUCT software is the possibility to automatically generate bending schedules from reinforcement drawings. At the end of my introduction an example will be given of the process of designing a caisson.
Because of the presence of parabolic curves, it was not possible to use the standard AutoSTRUCT software for designing the reinforcement in the superstructure. On some locations, the large number of different bar shapes, called for the need to automatically generate bending schedules. By using AutoCAD applications and standard AutoCAD commands the reinforcement was drawn in the 3D model. By applying the AutoSTRUCT user-interface it was possible to add reinforcement information to these 3D lines. It was then possible to use the standard AutoSTRUCT option to generate the bending schedules.

4.4 Production status

The SBF database mentioned above, contains progress control information in alpha-numeric format (Artemis). In the realization phase, this information has been used to present the production progress in a graphical manner. For this case two AutoCAD application have been developed to read the information from the database and to generated a 3D progress drawing. These drawings have been generated for the progress on the prefabrication yard, and for the progress offshore. The slides show professional visualisations of these progress drawings.

4.5 Presentations

Figure 7. Equalizer at transition slab

During and after the design process, 3D colour renderings have been made for
studying specific design problems, and presentation purposes. An example of this is the detailed engineering of the transition slab and equalizer in the expansion joint of the railway girder (see figure 7), which was visualized for evaluation by the engineering department.

5. A DESIGN EXAMPLE
5.1 Introduction
As mentioned before the reinforcement drawings in the substructure of the West Bridge have been prepared with AutoSTRUCT. About 400 of the 1000 reinforcement drawings are prepared using this RC detailing package. To indicate the working method, an outer wall of a caisson will be designed starting with the dimension drawing and ending with the reinforcement bars ready to put in position.

5.2 Reinforcement detailing
Starting with a dimension drawing the CAD engineer uses AutoSTRUCT for designing the reinforcement (see figure 8).

Figure 8. Reinforcement outer wall caisson
The software assists the operator in a number of ways: i.e. automatically taking care of concrete cover, placing of the reinforcement bars in the correct layer, automatic calculation of the number of bars, etc.
In the Storebælt project, a database was used containing all reinforcement bar data. This information has been used by the CAD engineer to try to minimize the number of different bar shapes. This guarantees a more economical design, and an optimization in the use of the cut and bending machine. Due to the repetitive character of the project the number of different bar shapes have been kept very low.

5.3 Labelling reinforcement
When the reinforcement drawing is finished, AutoSTRUCT is used again to provide the bars with a label number. In the end this number appears on the tags which are tied to the reinforcement bar bundles on site. When generating the label numbers, AutoSTRUCT consults the database mentioned above to check if a bar that is going to be provided with a label number, already exists in the database. If so, the bar will get the same number, otherwise the database is scanned for the first available number, which is then used. In this project, with a large scale of repetition, this working method has been proven to be efficient. If these functions were not available the site would have been filled with lots of identical bars, coded with different numbers.

The bars are coded with a number starting with two digits, which stand for the diameter of the bar. The remaining three numbers of the five digit bar number, are a running number. The bar with the number 16001 is the first 16 millimetre bar in the project.

5.4 Bending schedule
When providing the reinforcement drawing with label numbers, all information regarding the bars, is written to an ASCII file. This file is then used for generating the bending schedule (see figure 9).

It is not economical to bring the cut and bending machine in action, if only bardata from a single drawing is available. This would force the machine to change the cutting and bending parameters too often, which slows down the process. To eliminate this problem, it is possible in AutoSTRUCT to combine any number of bending schedules together to create one large bending schedule. When creating the combined bending schedule, a database file is created, which can be fed to an optimization program for the cut and bending machine. The same database file is used to update the database with bar numbers mentioned above.
5.5 Cut-to-length optimization
The file created by AutoSTRUCT has to be converted before it can be used by the cut-to-length optimization software. This CAD-CAM step links the automated process in the engineering office with the automated process on the prefabrication yard.

The cut-to-length optimization software is designed such that, after optimization has taken place, the cut and bending machines can be supplied with the necessary data for automatic operation. The objective of the cut-to-length optimization is to increase production and at the same time reduce the proportion of scrap and sub-lengths. Increased production is achieved by combining bar diameters and by eliminating the input time on the machine.

5.6 Cut and bend bars
The last step in the process is the cutting and bending of the bars, using the fully automatic Peddinghaus cutting and bending machines. The data created by the cut-to-length optimization software can be processed by the computer, build into the cutting and bending machines. The machines deliver the bars following the specifications, which are then bundled, labelled and stored.
Precast concrete silo structures in Russia
(design, manufacturing, erection)

F. Issers
The paper deals with the main requirements concerning precast concrete silo structures and their design in Russia. The classification of structures according to their fabrication and erection procedures is given as well as examples of most popular designs of circular and rectangular silos in reinforced and prestressed concrete. Some design procedures are proposed accounting for the effective behavior of structures and favoring their optimization.
In Russia the silo structures are constructed mainly of reinforced concrete. The year volume of its usage in silo structures is about 1.5 mln m$^3$. For industrial bulk materials storage the cast in situ concrete is used as a rule. The most part of silos construction is granary construction, more than 90% of them are built of precast elements (1.0 - 1.2 mln m$^3$ yearly)

The silos may be separate or blocked in silo blocks and disposed in one or several lines. Silos whose diameter exceeds 12m are made separate. The silo may be of round, square, seldom polygonal configuration with linear disposition in plane. The overall layout is unified. The distance between adjoining silo axes is made equal to 3, 6, 9 or 12m. The heights of silo walls, sub-silo and over-silo floors are made multiples of 0.6m.

The ground dimensions of silo blocks are limited by the necessity to arrange expansion joints. The maximum length of silo block is 48m. In case of ordinary soils it is recommended to make the ratio of width to length no more than 1:2 and up to 1:3 for linear silo disposition. With greater ratio the building behavior under general bending is to be checked by calculation.

Calculating silo buildings the loadings and influences are accepted according to the Construction Regulations. One also takes into account the loadings specific for silos produced by horizontal and vertical pressure of bulk materials on silo walls, pressure of the air pumped into the silo by active ventilation, gasation, homogenisation and pneumatic discharging of bulk materials. The climatic, technological, thermal loadings and a number of other set by Regulations are also accounted for/1,2,3/.

The method to determine horizontal pressure in silos for industrial bulk materials is analogous to one accepted in ACI 3/8, DIN 1055 and other European countries' Standards.

For grain silos the horizontal pressure determination is based on probability method of loading rationing. Experimental statistical loading from grain pressure is substituted by an equivalent one composed of a loading calculated by Yansen formula and a local loading: band, ring or local acting on certain area of silo wall /4,5/.

Analysis of silo walls consists of separate silo analysis and analysis of spatial silo system. The stresses inside reinforced concrete walls are determined accounting for three-dimensional behavior. When
determining the efforts in vertical sections of round silos it is allowed to consider these silos as separate closed cylinder shells. The walls of silo blocks formed of rectangular silos are permitted to be analyzed as horizontal frame structures.

According to the Design Regulations the walls of reinforced concrete silos are to meet the requirements of bearing capacity calculation (limit state of the first group) and of normal operation suitability calculation (limit state of the second group). The calculation for the limit state of the first group is to provide the structural strength and the calculation for limit states of the second group is to preserve silo walls from appearing and excessive opening of cracks.

For rectangular silos the wall deflections are also limited. The small cycle load changing is accounted for in the determination of crack opening width.

In precast silos the concrete of class not below B22.5 is used. The wall thickness of precast elements having rectangular section is not less than 40mm with minimum edge depth being 100mm. The wall thickness (in cm) is determined by a formula \( t = 6 + \frac{d_1}{2} \), where \( d_1 \) is external diameter of silo expressed in m.

As horizontal reinforcement bars of A-III class and 3-5mm diameter wires of Bp-1 class are used. It is allowed to use also A-II and A-I class reinforcement (for structural reinforcing).

The design and erection experience has showed that for precast prestressed elements it is advisable to use high strength reinforcement wires and seven-wire cables of K-7 class having high strength characteristics, reliable adhesion between concrete and steel, improved flexibility and practically arbitrary length. The usage of 6mm diameter cable K-7 reinforcement is particularly effective when the structures are produced by the continuous reinforcing method. The bar reinforcing of A-IV : A-VII classes is also applicable.

Precast prestressed walls are recommended to be provided with symmetrical horizontal reinforcement; it is allowed to use individual reinforcement placed of the section axle or winded outside providing reliable protection against corrosion.

Between precast walls of adjoining silos a 30 mm wide vertical joint is to be provided for 3m diameter silos and a 40mm-wide one for silos having diameter 6m and more. In square silos the joint is to be at least 30mm. Precast elements joints are to be protected from
atmospheric precipitation by constructive methods or by protective sealing.

Horizontal joint between precast elements are filled by a of B10 class concrete or a mortar not worse than 100 grade.

In the walls of prestressed silos with reinforcement tensioned in open channels or on the structure surface the fine aggregate concretes and cement-sand mortars of no less than 150 grade are used to protect reinforcement from corrosion and mechanical damages. When the reinforcement is placed in closed channels one uses also cement mortar with special additions in cases of necessity. The mortar is to be no less than 300 grade and to have necessary mobility.

According to the fabrication and erection mode precast prestressed reservoirs may be classified under two main groups:
1) silo blocks with walls of plant-fabricated three-dimensional blocks;
2) silo blocks and separate silos with walls of in-situ assembled structural elements.

The first group of structures permits to erect silo blocks with minimum in-situ expenses but the capacity of a separate silo is limited by conditions of element fabrication and transportation.

The second structure group is suitable for large capacities.

Three-dimensional ring elements may be plant-fabricated. Accounting for transportation conditions their diameter for cylinder silo is to be up to 3m. Unified solutions envisage two or four blocked silos disposed in two lines. They are used for industrial bulk materials with density up to 1.6 t/m³. The reservoir height is 15.6m, precast sub-silo floor is 3.6m high. Ring elements have outer diameter 2.97m, height 1.18m, wall thickness 80mm. Concrete of B25 class, horizontal reinforcement of A-III class steel with 8mm diameter and 160mm spacing are used. The rings are placed one on the other and joined with cement mortar. Adjoining silos are connected by reinforcing net disposed in horizontal joints: vertical joints between them are subsequently grouted.

Fig.1 Layout of precast block square silos
a - through cut; b - vertical joints bonded
Technical adaptability of fabrication, uniformity, convenience for transportation, storage, erection and a number of other factors are important for precast structures.

Accounting for all that the square silos are most applicable in the first group of the accepted classification. Their are to be cut in horizontal direction into separate three-dimensional elements of a size corresponding to the ground size of one silo. There are two types of three-dimensional element layout represented on Fig. 1. According to Fig. 1a scheme it is purposeful to accept even number of lines to have three-dimensional blocks put in the corners; flat panels are put between blocks along the outer perimeter. According to Fig. 1b the corner elements are added in border silos. This silo block layout is preferable because its spatial rigidity is considerably higher. The element connection in horizontal joints is carried out by cement mortar.

![Fig. 1](image1.png)

![Fig. 2](image2.png)

Fig. 2 Element connection in three-dimensional blocks silo

In initial design solutions precast element walls were of double-T and U-bar crosssection. vertical joints were of combined type — welded and bolted (Fig. 2a, b). Exploitation and construction experience has showed several defects of such structures (Complexity of erection, possibility to store only unslumping materials etc.).
Unified designs of silo blocks of 3x3m square silos have been widely applied (Fig. 3). The silo walls crosssection is rectangular. To protect horizontal joints from water permeability the outer walls are made with structural protection; their thickness is 160mm; inner walls are 100mm thick. The necessary rigidity of structures and joints is provided by brackets whose configuration and dimensions are chosen in such a way that upper and lower edges of adjoining elements don't create terraces. The connection of three-dimensional blocks with flat panels and corner elements is realized by identical 22mm diameter bolts with 400mm height spacing (Fig. 2c).

Fig. 3 Unified elements of square silo walls and spatial reinforcement frame

Prestressed elements having geometrical dimensions corresponding to those of reinforced concrete elements are also used. The precast elements are reinforced with high strength 6 mm-diameter seven-wire ropes of K-7 class with disposed in bundles uniformly by the height. By the tensioning the wire ropes are fixed on special supports inside
mould borders. When stripping the supports are removed and holes are grouted with mortar. In other variant the reinforcement is fixed on the concrete supports in the corners of the mould (Fig.4).

Equally with the 3x3m square elements the rectangular ones sized 3x6m are applied, however their use is less frequent. An inner wall placed in the middle of the span ensures a sufficient structure rigidity.

![Fig.4 Unified prestressed three-dimensional block](image)

1 - 6mm-diameter wire ropes; 2- reinforcement frame; 3 - concrete supports

Increasing of three-dimensional elements size over 3m leads to considerable transportation difficulties. So when silo of 4-6m diameter rings is to be erected, precast elements are fabricated at a casting ground accessible for the tower crane erecting the building. Such silo blocks are usually of reduced capacity and consist of no more than four silos.

In the case of element's ground dimensions exceeding 3m the elements generally assembled of separate parts at the building site. For square silos the purposeful element's size is 4x4, further increase leading to drastic growth of reinforcement requirement.

The silo blocks made of T-shaped ribbed panels or of panels with one side horizontal ribs are examples of silos designed in linear elements. The panels are assembled into large 4x4 elements at the building site by the welding of inserts.

Unstressed wall structures are used for 6 and 12m diameter silos for
industrial bulk materials. Precast wall elements are curvilinear. Their length is a quarter of a circle for the 12m-diameter and a third for the 6m-diameter. The element height is 1.2m. The crosssection is rectangular 100 and 160mm thick respectively for silos of 6 and 12m-diameter. The concrete is of B25 class, the reinforcement of A-III class. When assembling the vertical joints are secured by welding protruding horizontal reinforcement with inserts or by using steel straps welded to inserts of precast elements (Fig.5). The rings are mortar-fixed with two row bonding of vertical joints. The adjoining rings are connected by metal straps over the height.

Fig.5 Horizontal joints in precast silos for industrial bulk materials
1 - precast element; 2 - inserts; 3 - protruding reinforcement; 4 - steel straps; 5 - reinforcement net; 6 - concrete grouting

Precast cylinder silos for grain are built of prestressed industrially fabricated elements. In mass construction silos of unified design with diameters from 6 to 18m are applied. Having different geometrical parameters they are fabricated by the same technology and have similar joint connections. The methods of reinforcement tensioning and fixing are elaborated, as well as joint designs with effort transmission through the concrete or directly through the welded or bolted reinforcement. Vertical and horizontal joints of outer silos have
structural protection (Fig. 6).

The precast rings of 6m-diameter are assembled at the on building site of three or four curvilinear elements. The three-element ring design is preferable because the static unchangeability of the structure simplifies ring assembling; joint metal is also economized. Elements are fabricated of B22.5 class concrete, reinforcement is the 6m-diameter K-7 wire ropes. Central compression of the curvilinear element is provided by wire rope tensioning over concrete prismatic supports (Fig. 7). When erecting the rings are set on 30cm mortar layer. In horizontal plane the rings are connected with each other by bolts, then the joint is grouted with concrete.

![Fig. 6 Joint connection of cylinder-form silo prestressed curvilinear elements](image)

1 - curvilinear element; 2 - connecting bolts; 3 - inserts; 4 - connecting straps; 5 - reinforcement net; 6 - erecting bolts

Unlike 6m diameter silos the walls of 18m diameter silos are built of separate precast prestressed curvilinear elements with 6.96m long and 1.73m wide, the wall thickness is 14cm. The curvilinear elements design does not much differ from the one accepted for 6m-diameter silos [6]. Silo reservoirs are usually parts of a building having precast sub-silo and over-silo floors of reinforced concrete. However, there are some
designs with reservoirs erected directly on the basement slab. Most frequently this variant is applied for large size silos.

Precast elements of silo walls are industrially fabricated in moulds with rigid inside frame and hinge-hanged borders. The reinforcement of unstressed elements is realized through space cages and nets. The method of continuous reinforcing is the most widespread in the manufacturing of prestressed reinforcement cages. This method envisages the use of reinforcement reeling machines automatically laying out the high strength wire and wire rope reinforcement up to 6mm-diameter directly from plant coil and tensioning it.

While developing the precast silo design a group of analytical and theoretical problems was resolved favoring structure optimization.

For reliable spatial behavior of the building the joint work of precast elements adjoining by height is to be provided. Moreover the shear efforts in joints \( Q_{\text{max}} \) are not to exceed the holding ones \( Q_{\text{st}} \)

\[
Q_{\text{max}} \leq Q_{\text{st}} \quad (1)
\]

In the analysis scheme it was accepted that the vertical joint didn't perceive the horizontal forces and they are to be transmitted through horizontal joints. The holding forces were accepted equal to friction forces of the structure own weight with a part of bulk materials weight transmitted to silo walls and an additional compression when tensioning the vertical reinforcement. The friction coefficient value was determined by experiments on special samples imitating parts of precast silo walls.

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**Fig. 7** Prestressed curvilinear 6m diameter silo wall element

1 - prestressed reinforcement; 2 - concrete support; 3 - insert
For ring-form silos the distance between vertical joints of adjoining elements was determined from inequality (1)

\[ l_b \geq 0.9 \frac{P_h h_D m_b}{N_v} \]  

where \( P_h \) - standard horizontal pressure of bulk material at the depth \( h \) from the top of the filling; \( h_D \) - precast element height and silo diameter; \( N_v \) - total vertical force per unite of joint's length.

For square silos the behavior compatibility of adjoining lines is determined by a similar method. The further calculation is made either for each line separately or accounting for their compative behavior.

In silo blocks of three-dimensional square parts the shearing forces appear between adjoining lines because of differences in their rigidity. In case of simultaneous dislocations the shearing forces cause the moment redistribution.

Let us consider two arbitrary adjoining elements of bar system connected by elastic ties (Fig.8). The condition of dislocation simultaneity is the following:

\[ f_{12} = k \cdot f_{11} \]  

where \( f_{11}, f_{12} \) - \( i \)-th point dislocations of top and bottom elements accordingly; \( k \) - coefficient of horizontal joint yielding changing inside the interval \( 0 \leq k \leq 1, k=1 \) for equal dislocations.

Bearing moments of the main system \( M_{a1}, M_{a2}, M_{b1}, M_{b2} \) are equal to the algebraic sum of tie moment \( M_{su} \) and a moment caused by the joint yielding \( M_{p} \) (for elastic ties) or by the adjoining silo charge \( M_{p} \) (for hinged ties).

![Fig.8 Analysis scheme and main system](image)

The system of \( n \) canonical equations is solved for possible combinations
of loadings and elements connections by hinged or elastic ties. When accounting for the deformation compatibility the bending moments increase in the crosssection of elements having smaller dislocations in case of separate structure behavior. The calculation analysis has determined the maximum values of bending moment in such structures [7]. This research being proved experimentally allows to develop and practically realize the silo connection without bolts (Fig. 9).

The design and erection experience has revealed the behavior peculiarities of ring-form precast prestressed silos. In case of bending horizontal loading bending moments appear in ring crosssections due to difference of form outline from circular $M_r$, the rigidity $M_r$ variable along the perimeter, the joint yielding $M_p$, and the loading $M_{p.u}$ irregular along the perimeter. The total moment of external outer forces is equal to:

$$M = M_r + M_b + M_p + M_{p.u}.$$  

To determine the $M_r$, the deformation of a unite width ring have been considered. The expression for ring dislocation is got from the condition that the energy of bending deformation on an elementary part is equal to the external loading the additional deformation:

$$\omega = A - \frac{2pr^4d}{EY(\frac{2\pi}{\alpha^2}-1)^2}$$  

then

$$M_r = p \cdot r \cdot \omega$$  

where

$$\omega = A - \frac{2pr^4d}{EY(\frac{2\pi}{\alpha^2}-1)^2}$$

$A$ - maximum value of initial deviation from circular form; $\alpha$ - central angle corresponding to the arc length of curvilinear element; $r$ - circle radius; $p$ - loading [kg/m].

![Fig. 9 Unbolted joint in square silos](image)

a - outer; b - inner

Calculations with (5) have showed that $M_r$ increases up to a certain
loading level depending on quantity of precast elements in the ring. With further loading and \( M_r \) decrease.

The joint rigidity may differ from main crosssection rigidity (Fig.6). The analysis of rings subject to local even distributed axe symmetrical loading has showed that for rings with two perpendicular symmetry axes the joint rigidity didn't influence force value. There is a force redistribution compared to rings with constant crosssection. For ring elements with joints having a single symmetry axe. For example, in three-element rings when the ratio of main crosssection and joint rigidities \( m \) is changing in the range of \( 1 \leq m \leq 500 \), the maximum bending moment increases strongly (up to 2 times) and the longitudinal force considerably decreases. When \( m > 500 \) the moment and the longitudinal force nearly don't change.

The bending moment \( M_r \) is determined by the joint angular dislocation. The developed method of analysis allowed to create optimal structures of precast prestressed silos. Experimental checking and construction experience showed high reliability and economical purposefulness of the structures.

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From masterplan to fabrication; integrated cost-estimation + CAD in structural prefabrication

W. Ehler
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FROM MASTERPLAN TO FABRICATION,
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1. INTRODUCTION

The focal point of any tender concerned with precast concrete elements is the Master
Plan in which the specific construction project is broken down into individual ele­
ments. Even when façades are to be tendered in "m²" units, they are estimated as
"piece" units in the prefabrication plant.

The individual element dimensions enable the order to be harmonized with the plant's
production schedule. This can already be carried out at the tendering stage if there is a
relatively high possibility of the contract being obtained. However it is always under­
taken on award of contract, possibly initially in the form of a rough schedule worked
out to ensure the full utilization of plant capacity and availability of the required
capacity, and to establish the operating sequence.

The specific dimensions of the individual precast elements are determined in coopera­
tion between the architect and the respective prefabrication plant. It is not possible to
specify the materials to be used and working hours required until these dimensions
have been established. Only then can the preliminary schedule be replaced by a final,
detailed schedule covering all facets of production.

Where the tender, design and production scheduling process is EDP supported, the
design data (CAD) in particular provides a wealth of information which facilitates
work in other sectors. When, optimally, an integrated system (CAD, estimating and
PPC-Production Planning and Control) is used, this provides interfacing information
streams which form the basis for a rational, redundancy-free execution of the contract,
ensuring smooth continuity during all stages from receipt of the order to final com­
pletion (incl. transport and erection scheduling).

This paper deals with user requirements in respect to this type of system and with its
advantages for the design of precast elements.
2. TECHNICAL EDP IN STRUCTURAL PREFABRICATION

2.1 Structural prefabrication and automation

Even today, the organizational and technical procedures in a plant producing structural precast elements differ considerably from those developed in the, at times, highly automated precast slab plants [1]. One major reason for this is certainly to be found in the more complex geometries of, for example, façade elements and columns for industrial buildings. Integrated data processing of all technical sectors is essential when also aiming to achieve a high degree of automation in the production of these elements.

2.2 Main components of technical EDP

Where it is possible to use EDP programs for estimating, CAD (computer-aided preparation of drawings), and production scheduling and control, these are part of the technical EDP in a prefabrication plant. The wage, finance, and industrial accounting sectors are obviously included in the commercial field of EDP applications. On the other hand there are also sections such as production data acquisition (PDA) or the management information system (MIS) which cannot be allocated to any specific sector. As far as the data is concerned they are closely linked with both sectors.

Further aid is also provided by, for example, structural design programs and specialized computers relating to the automats, which although clearly of a technical nature do not perform comparable core functions such as those covered by the other technical programs mentioned. However as suppliers of initial data or as ultimate data receiving point they are by no means unimportant.

If estimation, CAD, and PPC are all computer-aided, the dataflow shown in Fig. 1 should be achieved.

![Fig. 1: Main data-flow in the technical sector](image)
2.3 Types of estimating

Estimating covers tender, contract, and final production estimates.

Tender estimating determines the production costs on a unit basis and compiles these in a Bill of Quantities relating to the tender. The BoQ is not necessarily drawn up on a unit basis. Although the project information available at the tender stage sometimes calls for almost clairvoyant faculties on the bidder's part, empiric experience and the relevant legal/commercial preambles in the Bill of Quantities are of assistance when tendering. A critical processing and assessment of previous data is essential for assuring economic effectivity.

After an order has been awarded, the conditions of contract must be included in the tender in order to create bases for invoicing and the performance of contract. This is undertaken with the help of the contract costs estimate.

In many plants the additional stage, production estimating, is not carried out. In most cases these plants do not have piece rates or very specific cost-centre accounting and these would be the sectors providing the main bases for production estimating. This is carried out on the basis of all the design details of the individual element in order to finally establish standard operation times and production and material availability for drawing up a final detailed schedule, and to compare the resultant costs with the prices to be obtained.

Both tender and production estimating is carried out on the basis of a standardized per unit estimate, with all costs calculated on the basis of selected element dimensions. These are applicable in a series of user-defined formula in order to guarantee a computerized estimation achieved in a user-friendly operation even for complicated units. In production estimating, the formula results serve as typical input values for various time curves in order to be able to establish various geometry-related effects on the costs according to the degree of accuracy required.

2.4 CAD-drawings

CAD covers the preparation of Master Plans giving the precise number and exact position of each individual precast element.

The element drawings (one element per drawing) show the individual precast element complete with all details, all reinforcement, and all built-in components. As well as material grades, unit numbers, erection details and other clarification, an element drawing also comprises specific production instructions in respect to a special precast component.

Additional, normally small-sized drawings are made to show special built-in units to be produced in advance.

The specific possibilities for the use of CAD in prefabrication plants will be gone into in detail in [2].
2.5 PPC functions

All operations in respect to work preparation including production and erection scheduling with all the relating control mechanisms are included in the PPC sector. Extensive work preparation is more important for larger rather than for smaller plants. No production overview board is required with 10 possible mould locations, but with over 30 locations a visual control of capacity utilization is certainly not easily possible without this, or something similar.

With the number of people relying on information (depending on the size of the plant!), there is a rising need for appropriately processed data as a work and decision-making basis for all levels of the plant hierarchy. This paper assumes the need for a comprehensive works preparation and organization (WP).

In addition to capacity overviews, this type of WP prepares numerous works instructions intended to ensure the timely completion of contract with good utilization of capacity on as even a basis as possible. It serves as a central source of information for the status of precast elements which have either to be produced, or have been completed and delivered or erected, as production data is fed back via this program.

This feedback data provides the bases for the main commercial requirements and can serve as database for the actual cost accounting. However these works are mostly not processed in the WP department. Changes in production scheduling for very divergent reasons are an everyday occurrence in WP and considerable time, effort and expense is involved when no suitable EDP support is available in this instance.

Arranging for the availability of all personnel and materials is a further function of WP which will be looked into in this paper. The optimal reaction to deviations from schedule, which is the main control function, determines, inter alia, the overall deployment of personnel.

2.6 Main data flow in technical EDP

Sectors covered in the estimation, CAD and PPC functions have now been defined. The arrows in Fig. 1 show the information transfer and transfer path between the fields in question.

Estimation supplies data to the PPC system. CAD supplies both estimation (production estimating) and the PPC system. The actual PPC system does not supply constant data to the other sectors (exception: bases for actual cost accounting).

The main data flows are shown although the required exchange of information between the sectors to ensure the same data base has deliberately not been shown.
3. MASTER PLAN AS DATA SUPPLIER

The Master Plan provides the:

- general visual impression of the project
- no. of pieces of the various prefabricated elements
- main dimensions of the individual prefabricated elements
- essential tender information

and is therefore an important document within the overall tender framework.

In addition to direct pricing, production scheduling can also be worked out with sufficient accuracy on this basis. With complex construction projects, the automated EDP-related transfer ensures error-free management of the very extensive data. In contrast to the element drawings, the early availability of the Master Plan enables a practical preliminary run of the work preparation to be made.

The number of element drawings required can be taken from the Master Plan. This permits the retrieval of individual element drawings to ensure a prefabrication sequence in compliance with deadline and erection requirements.

Erection progress is frequently shown on the Master Plan, partly to give a quick visual overview and partly to permit the status (produced, stored, erected ...) of every individual element to be seen in detail. However this procedure is usually only used on major projects.

The Master Plan is the only document defining the position of each specific part.

On the basis of the Master Plan, harmonization of most details in respect to the geometry can already be undertaken in teamwork between the architect and the prefabricated element designer. As an early clarification of such questions can only be advantageous for smooth production, Master Plans gain additional significance.

4. THE ELEMENT DRAWING AS DATA SUPPLIER

4.1 General

The element drawing provides the:

- geometric and material definition of all details of a prefabricated element
- geometric and material definition of all reinforcement components of a prefabricated element
- geometric and material definition of all built-in components of a prefabricated element.

The exact loading and relevant erection weight of the prefabricated element can be calculated with these data. The precise listing of all materials provides the basis for the ordering and supply of same. Although specific design or textual instructions are
normally not given, construction of the mould is also carried out on the basis of the
element drawing.

The production estimation as per chapter 2.3 is based on the element drawing and the
production planning factors (number of moulds, final allocation to a specific mould…) as
precise deadlines can only be determined when all the exact dimensions are known.

One advantage of an integrated EDP application arises when the geometric dimen­
sions, grades of material, and surface finishes of all components of a prefabricated
element can be transferred from the CAD system to the estimation or the PPC system
at the press of a button, thereby excluding the additional effort and expense of data
processing. This must then be undertaken if, as mentioned in chapter 3, data of other
element drawings have to be entered in the system.

4.2 Other drawings

Other drawings are, for example, conventionally prepared drawings and CAD draw­
ings where the drawing elements cannot be referenced as numbered items. Built-in
parts with specific geometries having, for example, differing surfaces, which would
have to be taken from overlapping drawings and compiled into lists are examples of
such items. When there is no access to complex elements such as built-in parts or
reinforcements via their item number, selections for targeted automat control is not
possible. Such control is only feasible when the exact geometry is known.

4.3 Control of automated machinery

Whereas the total length and number of bending points is sufficient for determination
of the effort and expense involved in a production estimate for data collection of a re­
inforcement position, the full and accurate geometry must be available for the stirrup
bending automats [3].

The quantity of data which must therefore be collected from other drawings is very
comprehensive and consequently liable to error. However it must be carried out if,
for example, stirrup bending automats are to be used. By application of the integrated
system dealt with in this paper, the CAD program makes these data directly available
to the data managing and automat controlling program which nevertheless also has an
input component for the speedy logging of other drawings.

In the author’s opinion, control of an automatic concrete spreader, for example for the
concreting of complex columns, is impossible without direct CAD coupling. Practical
acquisition of outside data is inconceivable or undefinable, not only because of the
volume of data but mainly also due to the special problematic of 3D-data derivation in
the CAD system and the selective data takeover by the corresponding automat-related
computer.

Where, for example, circulating systemized moulds are used, in this integrated system
the construction status of each individual mould is graphically defined and accessible.
A prefabricated part can thus be graphically adjusted to fit any mould. In general, the
mould chosen is the one which is easiest to modify. The existing geometry data can be
retrieved by the automats controlling the modification and conversion of the moulds.

4.4 Built-in parts

Built-in parts included in the element drawings are only shown separately when they are non-standard. In such cases special drawings are made in order to make prefabrication possible. The steel plate shown in Fig. 2 is a typical example.

In the conventional preparation of drawings and when using non-specialized CAD programs, detail drawings are made using the same means as for the element drawings. In our specialized system these drawings can be fully generated at the press of a button without any such effort by using the macro-technique. This also includes all inscriptions.

Fig. 2: Steel plate with stud head bolts as built-in part

4.5 Master Plan

In the system presented, the Master Plan's main significance in respect to the element drawings is a result of the automated assumption of the main dimensions of the individual elements from the Master Plan. This take-over is achieved by a position-oriented management of the elements across the complete scope of all the drawings, and by the application of parametrized prefabricated elements. In addition, the joint distances given in the Master Plan are also taken into account in the calculation and presentation of such element drawings, thus excluding the main source of error - the transfer of dimensions.

5. DATA OF THE PPC SYSTEM

As already mentioned and can be seen from Fig. 1, the PPC component is not such a good source of information for CAD and/or estimation. It establishes time-related information for these data and thereby forms the basis for processing in compliance with scheduling, so determining the prefabrication sequence.

After award of contract the information of the Master Plan or the estimate can be automatically transferred to the PPC sector. Although data from the Master Plan are
better organized than those in the estimate of contract costs, this can be drawn on as an equivalent alternative source. The data are kept in list form (see Fig. 3) and are an essential tool in production preparation.

![Table](image)

Fig. 3: Information from Master Plan or Contract Cost Estimate shown in list form

The data listed are complemented by data from the element drawings, and by the production, loading and erection dates (with planned and actual dates), thus serving as core production preparation control lists.

With the element types, main dimensions, and piece per unit numbers contained in these lists, scheduled production space can be reserved sufficiently accurately when the full construction date details are added. It is therefore possible, for example, to see at an early stage whether specific elements must be subcontracted due to lack of capacity.

The materials management and control sector receives essential information from the PPC. This data is usually further processed in the commercial sector, being utilized for ordering, stock management etc.

The production estimate passes its results on to the PPC system so that the rough planning provided by the tender/contract costs estimate can be replaced by more accurate costs. If no production estimate has been carried out, at least the exact number of pieces per unit should be included in the production planning. Order deviations are quite frequent and are usually only evident on submission of the respective element drawing, thus calling for replanning.

Deadline postponements necessitate extensive replanning, often at short notice. Apart from production and other internal problems, site and progress-related problems for which the client may be responsible also arise. Irrespective of the cause, a feasible
replanning must always be undertaken bearing deadline and other contractual con-
ditions in mind. It is not easy to find the best possible procedure covering high utili-
ization of plant capacity, minimization of costs (mould modification and so on), and
deadline delays in respect to all projects affected. Due to the high expense, it is
usually only possible to check one solution on the production overview board. In
addition to the initial planning, the PC-EDP-component also enables complex re-
scheduling to be undertaken with only minor input. The degree of capacity utili-
zation (see Fig. 4) can be equally taken into account in both the alternative scheduling and
the final production sequence.

The planning comprises a complete schedule in which the rough and final detailed
schedules are integrated as it is based on a mixed database deriving from both the
contract and production estimates.

![Graph](image)

**Fig. 4:** Monthly overview for working hours and concrete consumption

The estimation and PPC component is based on a relational database management sys-
tem. Should the existing evaluations be inadequate, it is thereby assured that any ana-
lyses in respect to materials, hours, revenues ... are possible without any difficulty.

The information, data blocks, and evaluations just described can also be achieved by
conventional means. The advantage of an integrated EDP system as shown in Fig. 1
lies in the simple application and the speedy, redundancy-free availability of all existing
data for other sectors. Owing to the current, relatively high proportion of outside
drawings in the plants, provision is made at all points in the system for such data to be
processed, so that the other advantages can also be exploited in these cases.
6. OPPORTUNITIES FOR PARTIAL UTILIZATION OF THE INTEGRATED PACKAGE

6.1 General

In the following, the opportunities for using two of the components of this system in each case will be considered and assessed as to their practical application.

6.2 Estimation + PPC without CAD

It has already been clearly demonstrated in many details of the previous descriptions that this variation can be usefully applied in additional areas. Estimation can be used without restriction. To a very great extent the PPC sector can be supplied with data from the estimation sector and is therefore also fully operational.

More significant, and in some sub-sections unsolvable problems arise in the important automat control sector. A successful solution for a stirrup bending automat is not always applicable in respect to the manual data input for other automats requiring more complex geometry and therefore necessitating CAD coupling.

Disadvantages arise from the essential separate processing of the precise geometry, built-in parts, and reinforcement elements in respect to work estimation and subsequent works (materials management and control ...).

6.3 CAD + PPC without Estimation

The use of this combination entails limitations for the PPC sector.

The CAD sector data does not include any deadlines. The individual scheduling data are the outcome of a scheduling estimate based on the completion date or, in the case of comprehensive construction projects, on additional interim deadlines. The scope of this project-related data is very restricted. In the production planning, at times typical assumptions for the duration of the individual works or the job around time of the component per mould position would have to be presumed in order to obtain the most comprehensive EDP support. This is possible on the basis of production estimation data from an independent EDP system but is relatively complicated. The corresponding assumptions can be successfully stored as fairly typical and so enable a high scheduling efficiency to be achieved in all important sectors of work preparation including materials management and control and the other back-end job sectors.

The element layout of the CAD system provides the exact number of pieces per unit and built-in parts. Automat control is possible.

In all sectors having to be supplied with precise time-related data and costs from a production estimate, errors can arise in this constellation as a result of a lack of data or of data being transferred incorrectly. Effective data processing for actual cost accounting is impeded.
6.4 CAD + Estimation without PPC

This combination is only feasible for smaller prefabrication plants with a lower number of prefabrication stands and no work preparation department.

CAD is now being increasingly used even at the tender stage. However it cannot compulsorily precede estimating because of deadlines. It must therefore be assumed that CAD transfer to estimation is only practical in the case of award of contract owing to the extensive data. Costs from a production estimate can be easily obtained in this way and automat control is assured.

Quick and safe application of a PPC component with no access to data from the other sectors would seem to be impossible.

7. PROSPECTS

As a software producer which has made the prefabrication industry one of its focal points of activity, we have developed from being a purely CAD service to being able to offer an integrated EDP solution for all the technical areas covered by a prefabrication plant. As CAD supplier in constructional prefabrication we have been confronted with a series of problems which lay in the optimal processing of available CAD-related data. For two companies offering combined estimation and PPC software, data transfer could be elegantly solved via interfaces. Problem constellations from the automatization, which called for availability as scheduled and the management of comprehensive geometric data, were the main triggers to providing a complete solution.

There are a number of minor aspects
- Truck loading including lists
- Erection scheduling including all lists
- Actual cost accounting on various bases
- Graphically-aided allocation of elements to the specific moulds for the planning
- Graphically-aided allocation of elements to the specific moulds for the automatization
- Coupling to the operation data registration
- Coupling to accounting and other commercial sectors
- Supervision of tender submissions
- Preparation of delivery notes and invoices
- Management information
- Preparation of drawings based on parametric elements

which would have deserved more extensive consideration at some points. They are included in the system, but would have been beyond the scope of this contribution in discussion of the pertaining problems. The advantages described clearly advocate EDP integration of estimation, CAD and PPC in order to be able to further the possibilities for rationalization in prefabricated structural elements to keep pace with increasing market demand. This considerably widens the bases for a further automatization.
References:


Moving towards component system building (CSB)

O. Tupamäki
MOVING TOWARDS COMPONENT SYSTEM BUILDING (CSB)

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SUMMARY
To overcome the 3 Ds (Dirty, Difficult, Dangerous) syndrome, industrialization and automation must be increased in the construction industry in general. This leads us to believe Component System Building (CSB) together with Computer Integrated Construction (CIC) will be the future.

As an important actor in the Developer-Designer-Manufacturer-Constructor-User (DDMCU)-chain, the precast concrete industry should move toward integrated flexible building component manufacture. Also the customer and end-user satisfaction must be secured, of course. On concrete material this typically means High Performance Concrete (HPC) with better durability, total quality and price-to-quality ratio. On manufacturing techniques this means Flexible Manufacturing Systems (FMS) with one-of-the-kind series and just-in-time capabilities. And all this is to be run under Computer Integrated Manufacturing (CIM) principles.
1. CONCRETE INDUSTRY;
FROM TROUBLES TO SUCCESS, PRIMITIVE TO HI-TECH

1.1. Industry Analysis
During the past forty years the world cement production has increased ten-fold to 1,150 Mton. Yet in the rich world (typically Western Europe, North America, Japan) cement consumption has already peaked, and many everywhere forecasts go down-the-hill. At the same time, however, annual unit consumption varies from under 300 kg per capita (eg Sweden, UK) to over 800 kg per capita (Switzerland), [Fig 1: Cement Consumption per Capita in Selected Countries 1990].

The precast concrete industry has developed very differently as evidenced by precast concrete's share of the total cement consumption, which varies from a level of 10% (eg USA, Switzerland) to over 40% (eg Finland, Holland), [Fig 2: Precast Concrete's Share of Total Cement Consumption in Selected Countries 1990]. Due to the statistical differences, the figures shown in the Fig 2 may be slightly inaccurate depending on which all prefabricated concrete products are included in various countries.

As shown in Fig 3, in Finland we consume cement for precast concrete 160 kg per capita while in USA they consume less than a quarter of that per capita, [Fig 3: Precast Concrete's Cement Consumption per Capita in Selected Countries 1990].

At the same time the total construction investment variate from a level of mere 10% per GNP (eg USA, Italy) to almost double (eg Japan, Switzerland). While the use of different materials definitely depends on reasons such as traditions, building culture & housing preferences, standards, local prices, level of development, state of economics at a certain time etc, it would be important to study the reasons for the wide differences appearing in the cement and precast concrete consumption country to country.

The 150 years old concrete, as we know it, is attacked by other materials, particularly various new materials. The situation for concrete today might be similar to that of the steel industry. During the past fifteen years the steel industry in Western Europe and USA went thru a massive restructuring. Still today there is 30% over-capacity and business is bad. Here restructuring was not enough. Only those companies developing new products and qualities, novel production systems and business concepts are successful. This might give the concrete industry a model path to follow.

1.2. Ideas and Action Needed
Most of the world is now suffering from construction recession; USA, many West European countries, East Europe, even Japan. Forecasts are expecting stagnant development in general with one major positive exception ie Germany, which fortunately is the largest single construction market in Europe.

The construction slump makes life difficult for all the players in the construction industry. This is also true regarding the concrete industry, and it tends to call for actions with short term benefits. Nevertheless, we must work hard in order to
secure - and in many markets to increase - concrete's market share in the future. This means realizing fresh business ideas, activities to improve concrete's image and efforts towards better products and new technologies. And above all, observing the requirements of the customer as well as the needs and preferences of the end-user.

2. TOWARD COMPONENT SYSTEM BUILDING (CSB)

2.1. 3 Ds Syndrome Leads to Automation in Construction

The construction industry in the rich world, ie wealthy developed countries, is facing shortage of skilled labour. The result is high salaries, high costs and a risk of failing to meet tight time tables.

This situation is a result of the working environment and conditions prevailing on construction sites and in many factories as well. This syndrome is characterized by three Ds: Dirty, Difficult and Dangerous. Unless these problems are solved, the situation will remain unchanged.

By using machinery, equipment and other mechanized technologies, some of the problems can be solved. But the final and obvious, if not easy, answer is industrialized building construction and automation.

Automation is an easy answer for any industry with continuous, semi-continuous, large batch and even small batch manufacture. But it is not so easy to use automated processes, systems, robotics and information technologies effectively in construction which could be classified as one off manufacture. Each building is unique in the individual design, materials and technologies, and many independent parties are involved.

Industrialized building construction could be tried thru three different paths briefly discussed below [Fig. 4: "3 Ds Syndrome Leads to Automation in Construction"].

2.2. Component System Building (CSB)

In this approach typically large components are made in permanent factories and then taken to construction sites for quick and easy assembly. Various wood, metal and concrete component manufactures are already familiar with it. It is easy to introduce automation into a controlled factory environment even if one-of-a-kind production is needed, as is very often the case. This system is suitable for all kinds of projects, small or large, unique or repetitive.

2.3. Construction Robots

Japanese construction conglomerates have been developing different robots to take over various dirty, difficult or dangerous jobs on site. Results so far are not all promising: unique and difficult site environments make it difficult to introduce automation. This system is suitable for limited works on relatively large projects.

2.4. Building Systems Suitable for Automation

An alternative approach involves developing buildings or building systems which are more suitable for automated construction. However, this concept might be
suitable for large high-rise or standardized projects only. In addition, this concept requires fundamental changes in design, engineering, products and even material properties. Same is partly true for construction robots, too.

In summary, it appears that Component System Building (CSB) is the answer for most markets, and involves the lowest risk. In fact, a great majority of the experts in the international construction community sign on this. This should be a good sign for the precast concrete industry.

3. CSB-RECORD FINLAND
3.1. History
Some people call a Frenchman Jean Prouvé as the father of prefabrication because of his visions and practical achievements on light weight houses of wood with a steel frame in 1925-52. Yet micro-components such as bricks have been used since the Tower of Babylon. You also may call many magnificent buildings of the ancient Egypt prefabricated with good reasons; the stone components were made and finished in one place, then transported to and erected in the actual construction site. In newer times, colonial powers erected many buildings and other structures around the world made of steel components manufactured in Europe.

While the oldest concrete structures may go back to 7,000 BC, in Greek (emplechton) and Roman (opus caementicum) times major and still existing structures were made of concrete-like material. In fact Rome's Pantheon, built 27 BC under Augustus, was the largest concrete building in the world until the end of the 19th century, and the concrete conduits of the large Aqueduct of Segovia, Spain, are still in use today 1,800 years after construction.

Yet it took to invent the portland cement by Isaac Johnson 1844 until concrete structures really conquered the world. Already ten years later steel reinforcement was introduced, but it was a patent achieved in 1892 by François Hennebique which brought reinforced structural concrete to life.

There are some scientists who claim that the ancient pyramids were made of precast blocks of concrete-like material and not of natural stone. Whatever the truth may be, 5000 years later precast concrete came to existence at least. By 1920 a long list of precast concrete products from the early days "cement ware" to large reinforced structural components for buildings, bridges, marine structures etc were manufactured in the UK, USA and other countries.

The precast concrete industry in earnest was born to solve the housing shortage in Europe destroyed by the Second World War. The development of new component systems by individual companies took place independently in several countries. The systems were incompatible within each others and they had many technical, economical and other shortcomings. Only the best have survived till this day.
3.2. Open Systems, Big Achievements

In Finland the first precast concrete buildings were erected just before the Olympic Games 1952. Here "Porthania", a large multi-storeyed building of the University of Helsinki is worth of mentioning due to its total component construction; columns, beam, slabs, facades, all made of precast concrete.

It took some more time before the precast concrete construction really took off in Finland. In early sixties numerous blocks of flats were built in Helsinki utilizing "total element technology". At the same time internal migration from the countryside to towns was accelerating, and major contactors were commencing their large new town projects. This was also the time for the first permanent precast concrete plants.

While in most other countries their precast concrete systems were closed (patented/designated/sold by single companies), in Finland a nation-wide element system was developed and called the BES System. This system was open and easily accessible to all manufacturers. Partly thanks to this open standard, component system building utilizing precast concrete proved to be very successful. In fact it is used more in Finland than in any other country.

Partek moved into the precast concrete business in big way between 1969-71. The main product was Variax® pre-stressed long span hollow core slab, an essential component in the BES System. Since the mid-seventies Partek has been the number one supplier worldwide of precast concrete machinery and technology under the Elematic® trade mark. Today Partek Concrete Ltd is a leading precast concrete manufacturer worldwide, with factories in ten countries; Germany, Holland, Belgium, France, Spain, Singapore, Malaysia, Finland, Norway and Russia with additional markets in England, Sweden and the new Baltic Countries.

4. ADVANCING COMPONENTS MANUFACTURING

Henceforward I concentrate on manufacturing technologies; yet much could be said about building methodologies, design, logistics, assembly, maintenance etc. Our objective should be lean production, where firstly time and efforts consumed by the unproductive materials & products flow be minimized and secondly the actual value-adding conversion be made as capable and effective as possible. While talking about modern precast concrete manufacturing, we have to usually touch on three different technology areas, ie materials & processing, systems and information technologies.

4.1. Toward High Performance Concrete (HPC)

Concrete with compressive strength of 40 MPa can be found in some Roman structures, yet it is only recently that significant advances have been made in the development of concrete materials. As per new standards issued in USA, Canada, Norway and Finland, a high strength 100/110 MPa concrete may now be used. And scientists are looking forward to 150-300 MPa ranges. No wonder that more and more skyscrapers are made of concrete, including the 600 m high Miglin-Beitler Tower, the world's tallest building, to be constructed at Chicago.
Now it may seem as if the concrete science already had achieved everything. Nevertheless, active development work is still necessary. Here special attention should be paid to product properties satisfying the customer and end-user, such as durability, visual appearance, total quality and quality-to-price ratio.

We should be able to manufacture concrete products good for 500 years. Here, in particular, exposed architectural and other concrete structures are of intense concern. Better concrete matrix and surface qualities are a must against various attacking deteriorators. As said earlier, we have two millenia old concrete structures still in use, and buildings made of precast concrete 70 years ago are fully occupied. Also a study made recently on the world’s tallest free-standing structure, the CN Tower at Toronto slipformed 18 years ago, proves the good durability of concrete; in the course of time the compressive strength had increased by some 30%, the state for freeze-thaw durability was ideal and carbonation was so slow that a service life of 1100 years can be expected! This proves that we have the know-how, yet we have to get it into practise by large.

Yet, of course, it is not enough that material or a component product itself is durable. But the whole building should have a long and maintenance-free service life. This covers materials, their combinations, bonds, joints, fixing and total structures in various climatic environments.

The esthetic values of our products should be appealing to architects and pleasing to the surrounding community including an ordinary man on the street. Total quality does cover all the myriad features and properties of a product and related services to the customer’s full satisfaction.

Prices may go down along with more efficient production systems. Here again concrete’s properties and processing techniques have a major effect on manufacturability and thru that on total production costs.

For its many favourable features and properties, high performance concrete (HPC) is the answer to several or most of the said requirements.

In addition, environmental aspects must be observed, where in particular high energy efficiency thru a total life spiral (raw material, manufacturing, transport, construction, use & maintenance, dismantling/demolition, recycling) plays an important role. The enclosed illustration [Fig. 5: "Life Spiral; Building Components Life Cycles Analysis"] shows clearly that, inter alia, the long service life of a building and its ingredients is vital to save energy. Similarly, the building components to be dismantled and re-installed appear to ideally offer the best alternative for recycling.

4.2. Toward Flexible Manufacturing Systems (FMS)
Salaries and wages are to go up for ever, yet prices for robots, computers and softwares needed in automation are going down. Hence automation is one important way to increase productivity together with cost efficiency. For standard products automation has already achieved good results in the precast concrete
industry, yet flexible production in short or one-of-a-kind series is waiting for its accomplishment.

Automaton has not been easy to apply on production of facades and other architectural concrete components characterized by 3-dimensional shape, colours, special aggregates, various textures and high quality finishes such as Patina®, polishing etc. At the same time various quality improvements such as dimensional accuracy, better durability against polluted air and deliveries just in time (JIT) should be observed.

In Partek Concrete we have some of the most advanced factories and manufacturing cells in operation, yet we still target at considerably higher levels in flexible manufacturing systems. To demonstrate our objectives, I show you a video film describing some of our new systems modules completed and/or under development applied and simulated in our existing facade component factory at Belgium.

Today we already have in use a series of technologies with the 3-dimensional CAD/CAM capabilities. They are labelled as Dimensio™ Technologies after our first such achievement, ie the Dimensio™ CAD/CAM System for architectural precast concrete facades. This module, completed in 1991, makes any 3-dimensional mould directly from the designer's CAD data file without any manual work and utilizes recyclable mould matrix materials.

Other existing modules with CAD/CAM capabilities include Dimensio™ AutoTreat for sand-blasting, fine-washing, painting etc and Dimensio™ AutoPolish for grinding & polishing of precast concrete surfaces with free 3D contours. Also we have Dimensio™ AutoLaser, a laser measuring device used for mould assembly and remote-sensing quality control. In addition, for concrete mixing & casting and steel wire mesh fabrication we have facilities with stand-by CAD/CAM capabilities.

In the application at our existing plant in Belgium, some of these and a couple of other modules under development were simulated. If an intra-factory transport system called Solitaire was properly executed, productivity went up by 20%; this also proves what I said earlier about lean manufacturing. When other suitable modules were added, productivity increased another 20%. In some other factories the gain is even higher.

4.3. Toward Computer Integrated Manufacturing (CIM)
Information technology has not achieved too much in the construction business in general. Yet most international experts agree that Computer Integrated Construction (CIC) will be the future. The above means, inter alia, that building material & component manufacturers must be capable for enterprise integration, ie to communicate via information technology with the other players in the Developer-Designer-Manufacturer-Constructor-User (DDMCU) chain, [Fig 6: CSB & CIC in DDMCU].
As parallel with and complementary to the above, we also have to develop our factories toward Computer Integrated Manufacturing (CIM) to utilize CIC effectively and to be able to run a factory as a single intelligent automated machine. This ideal concept is fully applicable perhaps in a green field factory only, yet the same ideology can be utilized in separate CAD/CAM production cells and modules suitable for existing factories, too.

Here Partek appears as a forerunner exhibited with the realized Electronic Data Interchange (EDI) communication network with some contractors and gross sales agencies and the TeleRatas databank for building materials, components and structures on enterprise integration as well as various Diomensio™ modules and technologies in full scale everyday use.

[Video; 11 min]

ENCLS: Fig 1: "Cement Consumption per Capita in Selected Countries 1990"
Fig 2: "Precast Concrete's Share of Total Cement Consumption in Selected Countries 1990"
Fig 3: "Precast Concrete's Cement Consumption per Capita in Selected Countries 1990"
Fig 4: "3 Ds Syndrome Leads to Automation in Construction"
Fig 5: "Life Spiral; Building Components Life Cycles Analysis"
Fig 6: "CSB & CIC in DDMCU"
Fig 7: "Flexible Manufacturing Systems / Application & simulations on a precast concrete facades plant, Partek Concrete Belgium; General Plan"
Fig 8: "Flexible Manufacturing Systems / Application & simulations on a precast concrete facades plant, Partek Concrete Belgium; Dimensio™ AutoPolish"
3D SYNDBROME LEADS TO AUTOMATION IN CONSTRUCTION

In rich developed countries, the construction industry is facing a shortage of skilled labour, in some works in particular. This results in high salaries, high costs and a rate of falling behind of tight schedule.

This situation is caused by the working environment and conditions prevailing on construction sites and in many factories as well. This syndrome is characterized by three symptoms, which I call 3D (synonymous with the famous 3Ks in Japanese) as Dirty, Difficult and Dangerous.

Industrialized building construction and automation is the answer to this predicament. Three alternatives are discussed below, as it looks today:

![Diagram showing 3D Syndrome leads to automation in construction]

- **3D**: Dirty, Difficult, Dangerous
- **Automation**: Information Technologies, Processes, Systems, Robotics etc.
- **Building Systems Suitability for Automation/Robotics**
- **YES**: Easy to utilize automation in permanent controlled factory environment. Good for all glass, industrial projects.
- **NO**: Hard to utilize automation due to unique difficult site environment. Suitable for limited works on large projects.
- **Possibility to utilize automation**: May be suitable for large/high class or standardized repetitive projects.
As a leading precast concrete manufacturer worldwide, Partek Concrete Ltd believes that the Component System Building (CSB) together with the Computer Integrated Construction (CIC) will be the answer to various cost-, quality- and time-related problems appearing in the construction business.

This means, inter alia, that building material & component manufacturers must be capable for enterprise integration, to communicate via information technology with the other players in the Developer – Designer – Manufacturer – Constructor – User (DDMCU) chain. In order to utilize CIC effectively, the manufacturers have to develop their factories towards Computer Integrated Manufacturing (CIM).
FLEXIBLE MANUFACTURING SYSTEMS
Application & simulations on a precast concrete facades plant, Partek Concrete Belgium

General plan

Dimensio™ AutoPolish
SESSION 2

WORK PREPARATION/MANUFACTURING
Flexible production automation

L.N. Reijers
1. INTRODUCTION

This presentation deals with the manufacturing of discrete parts in series production as it takes place in the metalworking industry.

During the last thirty years Flexible Production Automation has slowly penetrated this branch of industry. At first in the form of programmable production machinery. The use of numerically controlled (NC) machine tools has now reached an economically significant penetration.

Recently industrial robots have entered the scene. After a spectacular start in the early eighties in the automotive industry, further penetration in other industry is progressing painstakingly slow.

In the eighties much emphasis was put on integration. First integration of production facilities: machines, handling and transport equipment were coupled into Flexible Manufacturing Systems. Integration took place both in the materials flow on the shopfloor and in the information processing and control.

Now much emphasis is placed on integration of the manufacturing process with the design- and process planning functions on one hand and with the production planning and control functions on the other. Final integration of automated systems in the three basic functions in a manufacturing company, design, control and the production process, is embedded in the concept of Computer Integrated Manufacturing (CIM).

Since the automated machinery applied in the metalworking industry will be different from equipment used in manufacturing for the construction business, this article will not go into this subject. Besides I have noticed that Robotics in Construction is becoming a field of its own that is already receiving much attention in Civil Engineering.

Rather the article will concentrate on the aspect of integration, as it has taken form in the CIM-concept.

2. THE CONCEPT OF COMPUTER INTEGRATED MANUFACTURING

2.1. Origins

The term CIM was coined more than twenty years ago by dr. J. Harrington. His vision of a company controlled by information systems dates back to 1969.

In his concept he developed the idea of an "area of non-departmentalised decisions": a management that spans the various departments within a manufacturing company.

Harrington says: "the old barriers will dissolve under the irresistible demands of new technologies and communication will flow freely from boundary to boundary in the company". He points at the similarity of this concept with the early handicraft-shops that were run by one man doing design planning and manufacturing.

As of today his 1969 vision still lies in the future.

However in the early eighties, with the emergence of computer-networks and practical database management systems, the CIM-concept returns.

The consultancy world is pushing the CIM-idea heavily: far reaching integration from the start is strongly advocated. This idea came from experiences from leading edge companies which had heavily invested in island automation. Because of system incompatibilities, integration at a later stage turned out to be very costly.

However implementing CIM in one big swoop turned out to be an impossibility.

Attitudes, procedures and organisation in the company were not prepared for a far
reaching integration of functions. Also CIM-components and -technologies were immature.

The euphoric expectations of the early eighties have died out. Now the approach is pragmatic and cautious: a gradual process of partial automation with provisions of integration at a later stage is the route to go.

A number of learning edge companies is now quite successful with this iterative process of structuring $\rightarrow$ automation $\rightarrow$ integration.

2.2 The heart of today's concept of CIM

In 1990 the society of Manufacturing Engineers, SME, from the USA presented a working definition of CIM [ref. 1]:

"CIM is the integration of the total manufacturing enterprise, through the use of integrated systems and data communications coupled with the new managerial philosophies that improve organisational and personal efficiency."

Computer Integrated Manufacturing concerns the integration of automations in three basic functions of a manufacturing company:

- design and process planning;
- production planning and -control;
- the manufacturing process.

This integration takes place in two forms: one is the integration of typical production processes and materials handling and the second concerns the integration of information processing in the company.

The CIM-concept is based on three implicit assumptions:

1. in the company partial automations (such as CAD- and CAM-systems) are operational, which are suited for integration;
2. the company information-structure lends itself for integration;
3. the company's organisation is suited for a far-reaching functional integration.

Many failures on the path toward CIM can be attributed to the fact that one or more of these conditions were not met.

Figure 1 symbolizes this integration and indicates that the computertechnology is the binding element.

Figure 1  CIM is the integration of automation in three basic functions of a manufacturing company.
Modern thinking has it, that each of the three basic functions must be viewed as an integrated chain of activities:

1. **The design-chain;** this is the non-recurring sequence of activities that starts with the first idea for a new product and ends with its introduction in the market. Presently such design activities consist of highly separated steps consisting of product design and -engineering, process planning and the design and realization of product specific tools. Now, in industry a high priority is given to shortening the time-to-market. The design cycle is compressed by performing the steps as much as possible in parallel.

2. **The manufacturing-chain;** this is the sequence of process-steps that starts with the purchasing of materials and components, and runs through parts manufacturing and assembly to the distribution of the final product to the customer. At present material flow between these steps is decoupled by stocks and buffers. Integration in the manufacturing chain leads to quicker production reaction times and lower work-in-progress costs.

3. **The planning- and control chain;** this is the planning in time of the manufacturing processes, based on sales predictions and customer orders. It also controls the material flow through the plant. Integration here makes the company more responsive to changes in the market and leads to a better utilisation of the company’s resources.

It is this thinking in terms of process-chains which must form the basis of the organisational and technical integration of the various functions, departments and groups. Once attitudes, methods and the organisation are adapted, partial automations and integration at a later stage can be successfully implemented. And finally the state of CIM will be reached.

A keypoint in the concept of CIM is that of "shared data": information that is usable and accessible by all functions in the company. See figure 2. The engineering database contains product data and process plans, which are structured in such a way, that it can be used by engineering, production and sales and service.

The production database contains information of customer orders, production plans and the status of parts and products in progress. It also contains information about all manufacturing resources within the company. These databases are up-to-date and accurate and instantly accessible to all groups that need the information.

External parties can have access to this information on a restricted basis. On the supplier’s side this may concern co-makers, in need of product data, process plans and production planning data. On the customers’ side it is distribution and sales that needs and feeds planning and financial data.
2.3 Driving forces

There are two factors that form powerful driving forces behind the CIM-concept. On one hand there are new technologies that enable far-reaching automation and integration from a technical standpoint. Primarily based on rapid developments in computer technology, together with the emergence of fast and reliable data communication techniques. This technology push is now beginning to coincide with a real user-demand. It is this confluence of technology push and user-pull that will bring CIM-development in an unprecedented acceleration in the nineties.

What exactly is the nature of this demand from industry? Changes in the international markets show the following developments:

- In the fifties and sixties there was a "seller's"-market; whatever was produced was promptly soaked up by the still unsaturated post-war markets. Cost was the dominating factor in competition. Simple standard products were produced in large series: "the economy of scale" was the keyfactor in production.

- The seventies and eighties showed a marked change; market saturation created overcapacity in production. Customers became quality-conscious and required customized products. Shorter commercial life-cycles, combined with a large variation in product-types, created the need for production in small series, with rapid change-overs. Flexible Production Automation was introduced although the technology was more expensive and less productive than the classical mechanisation. "Flexibility" was the catchword of the eighties.

- In the nineties it is the product itself that becomes more complex and system-like. "High-tech" and "high-fashion" is the message. Control of product- and production information is becoming dominant in this period, along with the old demands for high quality and low costs. Better control requires better feed-back of information. "Integration" is the keyword of the nineties. It stretches beyond the limits of the company. Inter-company chains emerge. Suppliers become co-makers, sharing product-responsibility and risk.
3. THE ROAD TOWARD CIM

3.1 Three stages of development
In the application of flexible automation to each of the main functions, production, product-design and control, roughly three stages can be distinguished:

- the first stage: stand-alone automations,
- the second stage: partially integrated automation,
- the third stage: CIM, fully integrated factory automation.

In the following paragraphs each of these stages will be described in more detail.

The first stage describes the degree of automation that has been attained by the majority of metalworking industries in some form or other: stand-alone automation.

Production.
On the shopfloor, a small percentage of machines used for parts production is now numerically controlled (NC). NC was the first technique in flexible automation that entered the industry in the fifties and sixties and is now relatively mature. Although penetration has been slow (less than 10% of all machine tools are now numerically controlled), it is rising rapidly. Due to their much higher output than conventional machines, NC machines now have become an economically significant factor in parts production.

The majority of the NC machinetools are purchased on a stand-alone basis and are scattered throughout the workshops as isolated islands of automation. Very slowly the youngest member of the family of flexible automated production machines starts to penetrate the workshops: the industrial robot.

Flexible automation is notably absent in assembly. Presently most assembly tasks are too difficult to automate at acceptable costs. One reason for this might be that assembly is an underdeveloped area in the designers mind. Leaving the problem of sticking their ill-designed parts together to this wonderfully adaptable, highly sophisticated and intelligent manufacturing resource: man.

The key to automated assembly lies in the design area, rather than equipping industrial robots with vision and other very expensive sensor systems. In any case assembly is potentially the most important application area of industrial robots.

Design.
In the engineering departments the use of computers as a design aid also started in the early sixties. First as an engineering analysis tool. Later with the emergence of affordable computer graphics: computer aided drafting. Now there is the rapid penetration of sophisticated "CAD/CAM" systems, along with inexpensive drafting systems. The majority being purchased as turnkey, stand-alone systems.

Control.
As to their control function, in the offices of production departments a multitude of partial automations exists, applying information packages to clerical tasks in production. These are either implemented on small stand-alone computer systems or appear as one of the many functional partitions in the central computing facility of the company. These automations pertain to a wide variety of tasks in production control, such as inventory control, scheduling, materials management and production planning. The degree of
The second stage is that of partial integration of automated systems.

Production.
Physically most noticeable is the trend to integrate production systems on the shopfloor: clustering a number of NC machine tools into Flexible Manufacturing Systems (FMS), that are capable of operating for prolonged periods of time with a minimum of human supervision.

Underneath it all is a far more significant trend: the reorganisation of the production from a process oriented to a product oriented arrangement. Using Group Technology, families of parts are defined for which production cells can be configured, consisting of a variety of workstations. In these production cells, which may or may not be automated, a succession of operations is performed, integrating all - or most - production steps, necessary to transform the part from raw material into finished product. When these workstations consist of NC machine tools, equipped with automatic handling equipment for loading and unloading and linked together by an automatic part transport system, all of which controlled by a central computer, one can speak of a Flexible Manufacturing System (FMS).

These systems represent a considerable investment and must be utilized to the maximum, in order to be economically justified. Preferably around the clock, getting as close as possible to the 8760 hours of operation, theoretically available each year.

For the supervisory personnel this means working in shifts, around the clock, which is now considered undesirable. In addition, in most Western countries, there are strong social pressures to further reduce the annual number of working hours. This growing discrepancy between the desired working hours for personnel and the required operational hours in the factory, is the main driving force toward the unmanned operation of production facilities. Truly unmanned operation requires 100% automation and puts severe demands on process control, or by the lack of it, adaptive facilities to compensate for unwanted deviations in the process.

The effort necessary to obtain unmanned machining is enormous. Figure 3 shows that at present, the economic optimum is still a long way from unmanned operations, aside from the technological barriers. This will prevent truly unmanned operations for a long time to come, other than in a few isolated cases.

Figure 3  Economic aspects of unmanned machining.
Figure 3 may not be as trivial as it looks. Often the additional costs of automation are hidden and the savings in costs of labour are not known for the various degrees of automation. Also this notion may be applicable to other areas as well, such as the automation of process planning. It indicates that there are sound economic reasons for restricting the degree of automation in various tasks. This often tends to frustrate automation specialists in the company and sometimes commercial suppliers, who – for different reasons – want to push the degree of automation to its technological limits.

Control.
In the control function we can see the coagulation of partial automations of a clerical nature into integrated Manufacturing Resource Planning Systems. Both scope and level of automation are expanded. Flexible Manufacturing System controls, with their scheduling- and dispatching functions, will be brought on line with the MRP system, exchanging and sharing data.

Design.
In the design functions a real integration of CAD functions will take place, encompassing most or even all products and production tooling in the company. Drafting, design, engineering analysis and the extensive use of engineering data files will be supported by subsystems that share a common database. The use of geometry files as one of the inputs necessary to generate a NC part program with the help of the CAD computer (presently called "CAD/CAM") will be integrated into a larger system for Computer Aided Process Planning (CAPP). Both generative and variant types of process planning techniques will be used in automating the process of work preparation.

Stage three finally brings about the total integration of the three major functions in manufacturing: CIM has arrived.
A network of computers spans the entire company. Each computer system being a node in the network that can communicate with every other node, either directly or via neighbouring nodes. Processing power is now completely distributed.
Shopfloor facilities are fully integrated with Manufacturing Resource Planning systems. Inventory control and materials management systems controlling the flow and storage of goods in the factory, will be linked to physical distribution systems in the commercial branch of the company, leading up to truly integrated Computer Aided Logistics (CAL) systems.
The basis of this revolution in manufacturing that takes us through these three stages in an ever accelerating pace, is the fusion of two rapidly developing technologies: production technology and information technology.
Production technology with its development in new processes, materials, tools and intelligent machinery. Information technology driven by the dizzying development in computer hardware, data communication, software technology and mass storage techniques.

3.2 Development in time
At what point in time will each of the three stages, described above, be reached in metalworking industry?
Of course not all companies are in the same stage at the same time. Some branches of industry may lag as much as twenty years in the implementation of automation.
Figure 4. roughly sketches the development expected for the industry in the highly industrialized countries.
At present we do not think that there is one company in the world that has achieved CIM in full width. Only a few companies in the free industrialized world can be said to have reached stage II. It is interesting to note that there are two classes of industries that are in the lead in achieving stage II.

The first class is characterized by large scale massproduction, such as the automotive industry. In their production, automotive companies have reached a high degree of automation through mechanization, which started long before world war II: the so-called Detroit-automation. Now, these companies are trying to increase the flexibility of their production facilities.

The other group is characterized by high-volume series type production. Led by the aerospace industry and the manufacturers of earth-moving equipment. These companies are heavy users of NC equipment and are now interested to increase the degree of automation in their factories, without losing too much flexibility (see figure 5).

Clearly the term "flexible production automation" must have been keyed by people in the
first group. Because every form of automation brings about a certain loss of flexibility (the most flexible production unit I know of, is a manual operated machine tool).

It so happens that both aerospace and automotive industries are leading in applying CAD. Also it is not difficult to predict that it will be the large aerospace and automotive companies which will first implement CIM.

There is virtually no country amongst the industrialized nations that does not worry about getting behind in the automation race. Regularly alarming reports appear. The message is the same: the industry in country X is falling behind; then follows a comparison with an idealized situation in Japan and finally more government support - and in some cases even trade protection - is called for.

Figure 4 also indicates that there will always be a number of companies that will not apply any form of flexible production automation. There is still a substantial number of handicraft-type firms, which in some industrialized countries is even on the rise. Of course the contribution of this class to the total value added in the industry is small.

Figure 5 predicts that it will not be before the late nineties that the "Median Metalworking Company" (MMC) will move to stage II. Or, in other words, that 50% of all companies will be in stage II. In view of the heavy emphasis in the literature on the new technological possibilities, this may seem pessimistic. However, extrapolating the present rate of developments in the average company, we feel that this timescale will be close to reality.

Before the MMC has reached the state of CIM, we will be well in the next century.

3.3 The ever changing emphasis in Metalworking Industry

The question is: will the various CIM-technologies finally converge into one generally accepted standard practice, or will it explode into myriads of different approaches?

Most likely the CIM-technology will grow towards one optimal concept, as is mostly the case with maturing technologies. However it may be expected that within this general framework many company- and manufacturing-specific CIM-solutions will emerge. As happens often we will spiral in circles toward the ultimate CIM-technology.

Part of this spiraling path is already visible.

In the early eighties in Metalworking Industry, there was a lot of interest for shopfloor automation. Industrial robotics, Flexible Manufacturing systems and automated product handling and transport were in the center of attention.

Figure 6 indicates that in the late eighties the focus of attention shifted toward production planning and control. MRP, JIT, OPT and Computer Aided Logistics were the keywords. Now a clear focusing on the design and process planning chain is apparent. The early nineties will be dominated by subjects as product structuring, concurrent engineering, design for manufacturing and assembly, product data interchange and knowledge based engineering.

These trends can even be quantified in terms of member of conferences, publications and research projects.

Will the focus of attention return to shopfloor automation by the end of this decade? I think so; after the successive rationalizations in the other two areas, conditions are right for the Grand Finale. The final integration will take place in the area of a manufacturing company in which most capital is tied up and where most of the company’s manpower is
Figure 6  Shifting focus in Metalworking Industry.

Whether this pattern of shifting management focus will be followed by in the construction business is, to me, an open question.

What should the management approach to the CIM-concept be? In the last chapter of this paper an iron-clad approach will be proposed: the vise-grip.

4. THREE MANAGEMENT APPROACHES TO CIM.

4.1 The bottom-up approach
At present it seems that many automation projects in metalworking industry came about through a bottom-up management approach. The bottom-up approach is characterized by a patchwork of stand-alone automations. Many of them simply "happened". Most often they are initiated at a low level of management and try to solve immediate, short term problems. "Bootstrap" financing is characteristic for this type of approach: an automation project must essentially be financed out of savings on the previous one, all within the budget of the department itself.

Frequently these automations duplicate present working methods and procedures. The departmental barriers remain. Only some manual labour has been replaced by an automated machine or computer. A lot of it could be termed "stealthy automation": automation sneaking in through the backdoor. Production engineering people replace a couple of manual lathes by a NC lathe when a new product is introduced. Management will allow this to happen because it is a low-risk investment and it requires no major changes in the organisation.

The disadvantages of this bottom-up approach are that the automations are suboptimal and that integration at a later stage will be very difficult if not impossible. In trying to arrive at integrated manufacturing systems, earlier stand-alone systems may have to be scrapped.
4.2 The top-down approach
Ideally, every automation project should be a part of an overall automation plan, which is derived from the company's long term strategic plan.
In order to ensure that every partial automation can be integrated in a future CIM-system, the automation plan should be worked out in great detail. It would require that all interfaces between subsystems be specified beforehand and it must be exactly known which task is going to be performed in what subsystem. For example: will NC partprogram editing be done in the NC controller, in the cell computer, or interactively - in the CAD/CAM subsystem?
However, implementation of an integrated automation system will take many years. It is impossible to define the final system configuration in the required detail that far in advance, if it were only for the technical possibilities, which change by the year. For instance increasing processing power of inexpensive computer-systems tends to draw more and more tasks to the local level. Only when an entirely new plant is installed at one time, will such a top-down approach be possible.

4.3 The vise-grip approach
The essence of the vise-grip approach, which is proposed in this paper, consists of planning and participation. It combines the top-down approach, establishing a comprehensive and coherent automation framework, with the bottom-up approach: allowing automation that fits in this framework, to emerge from the operational level, getting as much participation as possible from all people involved. Thus holding the problem of automation firmly in the vise-grip of a two sided approach.
The basic idea is not new; only very few companies seem to follow this path.

Planning.
It all starts with a corporate strategy, which is the long term strategic plan, that contains among others a market plan and a product plan (see figure 7). Without such a top level business plan, any automation plan is without a basis.

![Diagram](image-url)
The second input is a technological forecast on automation technology, as it applies to the company.

The corporate automation plan should contain an assessment of the present position, as well as the final goals to be set in the three major areas: product design, production-planning and -control and operation (the manufacturing process). The automation plan, which should pertain to a planning period of about ten years, must address the following areas:

1. the technical aspects; an overall view of the company’s automation structure, including a make or buy policy. Will the company purchase turnkey systems or will it develop the capability to develop its own tailor made systems, based on purchased components;

2. an organisation- and personnel plan.
   In stage III the organisation of the company will have changed beyond recognition. Information systems can span the departments, groups and subgroups, that must exist now, because of the limitations of the human brain.
   the jobstructure will have changed completely: most manual tasks of a repetitive nature will have disappeared. New jobs will emerge, which demand new knowledge and more creativity. A program to re-educate the company’s personnel must be designed in time, because these are long-term processes;

3. an investmentplan.
   A coherent long-term investment plan should be set up. In the present situation it frequently happens that an automation is economically justified, but the company has different priorities for the capital available for investment, so that the project is scrapped or postponed.

From this long-term strategic automation plan, an automation framework must be designed containing in more detail the path that must be followed in the next five years. The various subsystems with their specific tasks should be clearly defined on a functional level. Also the interfaces between these subsystems must be defined, at least on a functional level.
Databases associated with each subsystem should be defined, both in nature and in form. Also equipment to be used within the framework should be standardized as far as is feasible. This can help to avoid the trap of the multitude of incompatible computer hardware and software systems, that comes with the stand-alone automations, all requiring their own specialists within the company. Finally priorities must be set.
So far for the top-down part.

Participation.
Within the framework as much room as possible should be created for the people at the operational level to define partial automations. Operational managers know the problem areas where automation projects may pay off quickly. And they can best activate the people who are going to be involved; people on the shopfloor, in the planning department, in the storageroom and in the engineering department. Manual labourers, technicians, engineers and supervisors, all are needed to define the tasks that must be performed by the system, that is going to take over most of their tasks.
They alone know in sufficient detail the intricate information network that must be maintained to control the complex functions in a manufacturing company. They alone
have the knowledge of the informal system, that has grown out of necessity and that is recorded nowhere in the official company procedures.

Such as the very effective cross reference system that was embodied in a smudgy cardbox in the bottom deskdrawer of the foreman at the receiving dock. It was not part of the very expensive computerized inventory control system, because no-one asked the foreman for its existence. Missing this important checking function, the system could not operate satisfactorily. A costly patch had to be brought into the system later.

People at the workfloor must be involved. They must play an active role in the system specification. But they must be motivated to do so!

A cold and remote top-down approach, with unfamiliar specialists descending upon the group from the central office "up front", or even strangers from an outside systemhouse, trying to ferret out the present working of the group, may fail miserably without the full cooperation of the people involved.

Even if the system has been properly designed, for a long time to come there will be people around to interface with the system. They must feed it with the information it cannot retrieve automatically and they must interact with the system to be able to cope with unforeseen situations. They must even take over control in cases of emergency, for which the system was not designed to deal with. These people are an integral part of the automated operation. They also must be motivated to operate efficiently in this new environment.

... And there is no way to motivate people better then to involve them in the project from the very beginning.

Planning and participation. That is the key to the vise-grip approach, combining the advantages of the top-down and the bottom-up approach.

The automation framework will ensure system compatibility and thus increase substantially the chances for a successful integration at a later stage. And it will considerably shorten the decision time for each implementation, because the automation-plan has already been accepted throughout the company.

The bottom-up part of the vise-grip approach allows for low-risk partial automations that cause a minimum of operational disruption and that can truly get people involved. And people will still be the basis of the CIM-systems of the next century.

CONCLUSION.

The above is an overview of history, present state and "quo vadis" of Flexible Production Automation in Metalworking industry. I cannot compare this with the situation in manufacturing in the construction business. I will happily leave this up to the participants of this symposium.
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Automated production of GRC sandwich panels and system of quality control

E. Cziesielski
Annexation and distribution of ERC sponsored projects and activities of joint contractual arrangements.
AUTOMATED PRODUCTION OF GRC-SANDWICH PANELS
AND SYSTEM OF QUALITY CONTROL

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Biography:
Civil Engineer. - After study working at the Technical University of Berlin and
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Summary:
In order to be competitive, prefabricated building units should satisfy high
specifications and should be produced according to industrial methods.

The construction and the automated production of a sandwich panel will be
explained. The covering layers (skins) of the sandwich panels are made of
glass fiber reinforced concrete and the core is filled with polyisocyanurate-
foam. Securing the quality during development and construction of the
elements is of special significance. The elements of quality securing will be
explained.
1. INTRODUCTION
For external curtain walls exists frequently the handicap, that their own weight should be $g < 1,0 \, \text{kN/m}^2$ and also that their heat resistivity should be $R \geq 3 \, \text{m}^2\cdot\text{K/W}$. The specifications of these walls from the fire-protection and sound-proofing technological points of view, should be adatable to these requirements. As a solution for the development of such an external wall construction exists the possibility, to chose an original sandwich construction. The covering layers (skins) of the sandwich panels should not be made of reinforced concrete due to weight reasons, but of concrete which is reinforced with glass fibres.

The development of such an external wall requires, from the technological point of view, following measures:

a. Design of the wall and suitability test
b. Development of a suitable production technology
c. Measures for quality securing (TQC = Total Quality Control)

2. SANDWICH CONSTRUCTION
2.1 Wall assemblage
The firm Veldhoen, the Netherlands, used for the development of this external wall construction the experience with Durisol-External walls, which are produced by the firm since years (fig. 1)

![Assemblage of a Durisol-External Wall](image)

Fig. 1: Assemblage of a Durisol-External Wall
These walls are an original sandwich construction: The covering layers (skins) are made of reinforced concrete and the core is made of wood-chip concrete. The three layers of the walls are cast together so that a total bond develop (fresh concrete on fresh concrete). The wall thickness is 16 to 28 cm. The walls are produced industrially and they have a standard width of $b = 1.20$ m; the maximum length of these walls is 12 m. Thousands of square meters of walls were produced according to this system in the Netherlands, Germany, Switzerland and Austria.

The further development of this construction lies in manufacturing the covering layers (skins) with glass fibre reinforced concrete and the core of polyisocyanurate-foam. This foam has a temperature resistivity up to 140 °C (fig. 2 and fig. 3).

![Diagram of a sandwich wall with covering layers (skins) made of glass fibre reinforced concrete. (sec. A-A to fig. 3)](image-url)
The outer glass fibre reinforced concrete layer can be made of either washed concrete or it can be coated with a foil of PVC. Figure 4 shows photographs of completed buildings which are constructed using sandwich walls. The thickness of the glass fibre reinforced concrete layers is 16 to 18 mm. The thickness of the VIR-foam varies according to the total thickness of the elements.

Fig. 3: Mounting of a Wall and Longitudinal-Section.
Fig. 4: Completed Buildings using Sandwich Walls
2.2 Examination of the walls
To prove the suitability and durability of the walls, a series of investigations were conducted, of which the most important will be described.

2.2.1 Examination of the glass fibre reinforced concrete covering layers (skins)
The flexural tensile strength and the corresponding modulus of elasticity of the glass fibre reinforced concrete layer were determined using a bending test. For this test, specimens were taken in different directions from the glass fibre reinforced concrete layers. The specimens were taken in the production direction, perpendicular to the production direction and in an angle 45° with the production direction. It was realized, that no significant changes in the mechanical properties arise due to changing production directions.

Furthermore, freezing- and thawing-resistance tests were conducted in accordance to the DIN 50 014.

2.2.2 Durability
The durability of glass fibre reinforced concrete depends primarily on the resistance of the glass fibres to alkaline medium (concrete). In order to obtain a quantitative measure of the durability of the reinforcing glass fibres, an acceleration test was conducted.

To evaluate the aging behaviour of the glass fibres, the SIC-Test (strand in cement) is carried out (see fig. 5). On the other hand, in order to evaluate the long term behaviour of glass fibre reinforced concrete, the bending behaviour and the work capacity of suitable specimens are examined.

![Fig. 5: SIC-Test](image-url)
Through storage in water bath of higher temperatures and with the help of those from Arrehnius's descending relationships, a connection between the "fast test" and the long term behaviour of glass fibre reinforced concrete elements under natural weathering conditions can be found (fig. 6).

Fig. 6: Influence of the storage temperature on the decrease of the flexural tensile strength of glass fibre reinforced concrete (according to [2]).

According to [1], the ductility of glass fibre reinforced concrete made with portland cement (first generation of glass fibre concretes) decreases along with the decrease of its flexural tensile strength. This is not only due to the chemical attack of the high alkaline pore water, but mainly due to the accumulation of calcium hydroxide crystals on the filament surfaces which strongly reduces the displaceability of the filaments and fibre bundles. Realizing this, new cement-bound masses were developed (second generation of glass fibre reinforced concretes), by replacing the portland cement with mixed cements and pozzolanic additives. In this way, a considerable improvement in the carrying behaviour of the glass fibre reinforced concrete,
after carrying out an aging test, was achieved. The reduction value in the flexural tensile strength of the aged concrete is under 10% the strength after 28 days.

2.2.3 Experiments on building elements
To judge the structural behaviour of sandwich elements under windsuction loading, an experiment according to fig. 7 was conducted.

Fig. 7: Experiment to determine the strength of the sandwich elements under windsuction loading

The windsuction loading was simulated using a pressure pillow. In this way a uniform pressure was applied on the back side of the sandwich element. A factor of safety against windsuction greater than three was reached during the bending experiments.
3. PRODUCTION OF THE SANDWICH ELEMENTS

Firstly, the glass fibre reinforced concrete layers are produced on tables using shotcreting. The length of the plates are then cut in accordance with the requirements of the project. After reaching sufficient strength the plates are transported to the foaming plant. The glass fibre reinforced concrete plates are then put for foaming in shuttering plates which are 1,20 m high. The temperature of the shuttering plates can be raised. The distance between the plates is then fixed, along the long sides of the plates, according to the requirements. The foaming between the plates takes place in the direction of the breadth \( b = 1,20 \text{ m} \), by the length. The transport of a finished plate is shown in fig. 8.

![Transport of a finished plate in the factory.](image-url)
4. QUALITY CONTROL

4.1 Problem outlining

The term "Quality" is differently defined. ISO 8402 defines quality as "the totality of features of a unity regarding its suitability in order to fulfil the fixed standards". In order to be able to measure and judge the actual quality, a clear and settled definition of quality requirements between client and contractor is necessary.

The design of the European guideline plans to make the liability duration for building products and also for construction and design of buildings twenty years. The liability can neither be limited nor excluded. The obligation arises to reach through quality control a damage free and yet economic construction. A series of standards were initiated (ISO 9001 to ISO 9004, EN 29000) to support this goal. These standards give certain indications to quality securing measures and a systematic introduction in the principles of quality thinking.

Fig. 9 shows the causes of the non-compliance of aimed quality requirements in Germany due to human failure.

![Fig. 9: Percentage Distribution of Human Failure [3]](image)

Fig. 10 shows the causes of damage of 98 examined damage cases [3]. On the other hand, the decrease in the total costs after carrying out the TQC is shown in Table 1; the percentage figures refer to the contract value [3].
In summary, the urgency is clear, that quality securing is necessary due to the damage frequency and development in Europe (legislation).
4.2 Total Quality Management (TQM)

A quality securing philosophy was developed in the USA from the military point of view. This philosophy was then further developed by the electric- and automobile-industry in the USA and Japan. This "Total Quality" includes:

Total Quality means that the requirements and needs of the client should be analysed in the design phase and that the construction should be carried out error free during the execution phase.

Total Quality not only includes execution, but also design, service, management and finances.

Total Quality means therefore, that most of the departments and employee of a firm should be involved in the quality control.

In summary, the following elements of quality securing of a prefab-concrete factory can be given as orientation help:

1. Fixing the program for quality securing. The fixation should be discussed with the employee at their place of work.
2. The organisation of the quality control must take place in office.
3. The documents for carrying out quality securing (standards, guidelines, etc.) should be ready.
4. The construction documents should be layed out at the appropriate places of work.
5. The suitability of materials should undergo quality control.
6. Training of employee.
7. For carrying out of quality securing a management is to be developed (deviation from the specified quality must be reported and halting points should be given when a serious violation against the quality requirements is observed).
8. The quality must be inspected.
9. Rules should be followed in the same manner as when quality deviation occur (the next superior is to be informed).
10. Remedy measures should be developed for the case that deviations occur.
11. Quality securing measures should be documented.
12. The quality securing system should continually be examined and if necessary improved.
4.3 Current quality supervision during the production of the sandwich panels

To be sure that the end product is satisfactory it is necessary to know the quality of the GRC skins before foaming. Therefore, a plate of about 1 m² is taken out of the production. The plate is wrapped in PE-foil for seven days, after which 20 testpieces are cut out of it for bending-test, after seven days 14, 21 and 28 days.

From these tests we get the following informations: density, E-Moduls, EJ, LOP, MOR, thickness.

Additional tests were carried out in order to improve the product as well as to develop and check calculation methods; tensile strength on GRC strips, shrinkage/expansion in wet/dry on GRC strips, accelerated test, panel movement.

The foam is tested as follows: density, compression strength, elasticity.

The experimental results are recorded, stored and statistically evaluated using data processing systems. It was ensured that the sandwich panels show a good quality due to the continuing supervision of the production. The damage rate is minimal in comparison to the period in which production did not undergo any quality securing measures, although the concrete sandwich walls require a high standard of production.

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Automatic production of double wall elements

B. Stadlmann/A. Emsenhuber
Automatic Production of Double wall elements

Burkhard Stadlmann
Anton Emsenhuber

Contents:

1. Introduction
2. The Production Flow and its Machinery
3. The Control system of the Production Flow
4. International Marketing of Double Wall Elements
5. Conclusion

1. Introduction

We would like to present you a new concept of producing double wall elements and floor slab elements in one highly automated plant. It was realized three times within the last 15 months and further plants are scheduled to go into operation next spring with further improvements in machinery equipment.

Figure 1 shows the type of elements to be produced in this plant for those of you who are not so familiar with these products. The figure shows one double wall element and one floor slab element put together on site. The space between the two parts of the wall elements will be filled with concrete on site. In addition to these two types of elements there can be produced "double wall elements" with distance zero. That means that there is no space left between the two parts of the double wall. Actually it is like a massive wall but the production cycle is like a double wall.

The three plants in operation produce their double wall elements as well for small personal houses as well for large houses and for any types of industrial buildings.
2. The Production Flow and its Machinery

The Production is based on a pallet turn around system with several automated stations and some manually operated stations. Overall there are 6 persons working within the production, responsible for activities not yet automated and for the supervision of the machines plus one person (partly) for the electromechanical maintenance.

Figure 2 shows a schematic overview of this plant.

In addition to this figure 2 some short explanations about the production of these slabs and elements are necessary. The first step is the cleaning of the pallet. Afterwards a special multifunctional machine plots the shapes of the next slabs onto the pallet (scale 1:1) and positions the transversal shutterings according to the shape of the slabs. This machine fulfills all the handling of four different types of transversal shutterings, including the oiling of special parts of these shutterings. The second step is the manual completion of the shuttering using reusable steel elements and polystyrene parts. The third step is the automatic positioning of the reinforcement, both transversal and longitudinal reinforcement, each steel bar according to the CAD-data. This reinforcement center is equipped with all necessary mechanical and control details for automatic operation. The robot as a central part of this center positions the lattice girders too. The fourth step is the manual completion and check of the reinforcement. The fifth step is the automatic concrete distribution. That means to lay automatically the right amount of concrete onto the right spot. The concrete distributor is designed to operate as well longitudinal as well transversal depending on the geometry of the element. The sixth step for the double wall elements only is the turnaround station to put together the two parts of the double wall. The upper part of the double wall is fixed by vacuum on the turnaround station for highest flexibility and to enable the production of double wall elements with distance zero. The seventh step is the curing of the concrete in the curing chamber. The eighth and last step is the removal of the slabs or the wall elements from the pallet. The slabs are organized in stacks due to the requirements at the site.

Some additional data: Pallet size: 3 times 10.5 Meters
Cycle Time per station: appr. 15 minutes

3. The Control System of the Plant

As our company is the main supplier of the the control system I want to inform you about some further details of this topic. The control system has three sections:

- The CAD System
- The main plant control computer
- The machine controllers

Figure 3 shows the hardware configuration and its communication facilities. As it can be seen from the diagram all computers of the CAD system and the plant control system are personal computers. This offers a standard low cost hardware concept and ensures highest flexibility for future developments both on costumer side and on computer technology side. The machine controllers are equipped with PLCs partly amplified by a local process computer for those PLCs with complex arithmetic demands.
All computers are connected to local area networks (LAN). On the CAD/CAM side it is a NOVELL network on the production side it is a field bus for process communication. The software of the plant control computer runs under the operating system OS/2 and makes extensive use of its graphical windows-interface called presentation manager and its multitasking capabilities.

The basis for the whole production is of course the CAD system. Its output is directly connected to the production. The CAD system has a general input for the building layout. It can be entered into the computer either by manual input or by direct file transfer on floppy disc from the architecture’s CAD system by dxf interface. Beside this standard dxf interface the AIA system supports the manual input in a very efficient way. After this input the processing of the slab elements is separated from the processing of the wall elements. All detailed data for the production are calculated by the CAD system. The necessary information is entered interactively by the operator. Figure 4 gives an overview of this data flow within the integrated AIA CAD/CAM System.

In addition to the “office based data flow” within the CAD/CAM system Figure 5 shows the data flow within the production plant between the main control computer and the machine controllers.

The Main Control Computer:
For the operator of the plant the main control computer is the central control facility where he can influence many features of the production and where he gets all information about the availability of the plant. The main control computer has to carry out the following tasks:
- Calculating the production sequence considering the individual parameters of the operator.
- Continuous display of the production status including display of actual errors
- Generating of various reports on production output, raw material input, error statistic, cycle times of the pallet turnaround system
- Various additional display functions.

The calculation of the production sequence is an essential task concerning the efficiency of the production flow. It has to consider the two different parts of the double wall elements, the floor slab elements and in some plants massive elements too. The operator can influence this automatic calculation by a various list of parameters and if necessary he can do the job manually. The computer checks the production time of each element and calculates the sequence accordingly. It ensures that the two parts of the double wall will find together in the correct way, and that all elements leave the plant in the correct sequence for the site.

As an example of statistical reports we show you in Figure 6 a short protocol of the production. It is designed as a short information for the manager presenting him the most important figures of the production day or month.

4. International Marketing of The Double Wall/Floor Slabs

In Germany the floor slab element is already well known and occupies a market share of nearly 80% whereas the double wall element yet has to gain ground. A similar development is seen in Austria. Currently there exist several precast concrete plants producing exclusively double wall elements but there are also 3 precast concrete plants in Germany as well as Austria capable of
producing double wall as well as floor slab elements on the same pallet rotation system. As these "value-added" factories would virtually be capable of producing whole houses, they seem especially suitable for markets, where conventional construction methods are simply not sufficient to match the gigantic housing demand, like in Thailand, Korea, Singapore, Malaysia or Iran. But this is not the only "sales argument", as we found out after surveying various markets. Depending on the countries, there exist different sets of arguments for the introduction of the multifunctional precast concrete plant, which is described briefly below:

arguments for introducing the precast concrete plant | countries
--- | ---
possibility to produce whole houses | developing countries
lower cost than formwork | USA, Thailand
very high productivity (matching high demand) | Thailand, Singapore, Iran,
labour saving technology | Malaysia, Korea\nlogistics advantages (no heavy-duty cranes) | Japan, countries with high labour
countries with high labour costs | Korea, Iran
concrete houses accepted widely | Korea
earthquake resistant construction | Iran, Japan

Considering this array of arguments we can identify the following overseas markets as promising: Korea, Iran, Thailand, Singapore and Japan. As new construction methods need to be approved by official or semi-official organizations, the introduction of the precast concrete element into new markets is very time consuming.

In order to be able to calculate the costs for the production of whole houses using double wall elements as well as floor slab elements we were especially interested in the cost structure of these precast elements. A survey done by us in summer 1992 revealed the following:

<table>
<thead>
<tr>
<th>total cost per m² DM, %</th>
<th>double wall</th>
<th>floor slab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>119,71</td>
<td>100%</td>
</tr>
<tr>
<td>1. manufacturing cost</td>
<td>67,50</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>1.1 material cost</td>
<td>24,82</td>
</tr>
<tr>
<td></td>
<td>1.2 labour cost</td>
<td>10,07</td>
</tr>
<tr>
<td></td>
<td>1.3 energy cost</td>
<td>1,80</td>
</tr>
<tr>
<td></td>
<td>1.4 depreciation, interest</td>
<td>30,83</td>
</tr>
<tr>
<td>2. transportation cost</td>
<td>7,11</td>
<td>6%</td>
</tr>
<tr>
<td>3. erection cost</td>
<td>41,10</td>
<td>34%</td>
</tr>
<tr>
<td>4. finishing cost</td>
<td>4,00</td>
<td>3%</td>
</tr>
</tbody>
</table>

As we have interviewed only 3 companies which had different automation levels and different logistics systems, our cost estimates may vary and are therefore not 100% accurate. But it is now possible for us, to estimate the total cost of a whole house anywhere in the world, using a set of local cost values for material, energy and labour.

5. Conclusion

We presented to you a highly sophisticated and highly automated plant for the combined production of double wall elements and floor slab elements. Due to the experience of the planning team of Mr. Reymann and all suppliers our costumers consider the plant as very
efficient and equipped with many well thought out details. We gave you some ideas of our control concept, and of economic considerations concerning double walls. Further ideas to this automatic concrete plant will be presented by Mr. Reymann in his paper later this day.
FIG. 1 DOUBLE WALL ELEMENT AND FLOOR SLAB ON SITE
FIG. 2 PRODUCTION FLOW

- manual shuttering
- cleaning shuttering plotting
- automated
- buffer
- buffer
- reinforcement
- automated
- removal of ready slabs and wall elements
- curing chamber
- turnaround table
- concrete distribution
- automated
FIG. 3 HARDWARE CONFIGURATION
FIG. 4 AIA CAD / CAM System

- CAD processing WALL
  - double wall
  - solid wall
  - brick wall

- CAD database

- calculation production data wall

- plant parameter wall

- individual slab plan

- calculation production data floor slab

- pallet layout

- production database

- NC-generator

- main control computer

- listing generator

- plant parameters floor slab

- billing reinforcement listing etc.
FIG. 5 INFORMATION FLOW WITHIN THE PLANT

- CAD-prepared CAD-data
- system
- prepared CAD-data
- plant control computer
- NC-data
- begin of production
- end of production
- error report
- status information
- consumption of raw material
- commercial software system
- production report
- database for NC-data etc.
- machine controllers
- software NC-data etc.
- system raw material
- begin of production
- end of production
- error report
- status information
- consumption of raw material
Characteristic
of element production

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Period: from 08/09/92 06:00 until 08/09/92 22:30
pallets: Pos. 1749 Pos. 1810

Produced elements (wall/slab): 1216.54 m²

Number of pallets: 62 pcs
Pallet occupancy: 60.70%
Percentage of non-standard slabs: 37.50% pcs
Concrete consumption (reference): 59.82 m³
Concrete consumption (delivered): 61.80 m³
Deviation (reference/actual): 3.30%
Steel consumption - steel rods: 4513.40 kg
- lattice girders: 1934.30 kg
Specific steel consumption: 5.3 kg/m²

Production time with 7 manual workers: 107.30
Specific production time: 0.088 h/m²
Production output: 73.70 m²/h

Fig. 6: Main control computer report
Precast foundation elements; from piles to ground floor elements

G. van der Laan
Ringvaart B.V. is a company which has been specialising in the manufacture of concrete piles for years. From Hillegom a central location in the west of the Netherlands, these products are delivered to all parts of the Netherlands, as well as Germany and Belgium. The company has built up a good market position as a result of keeping up with the latest advances and developing new ideas related to the technology of foundations and concrete, as well as manufacturing processes, for both pre-stressed and traditional reinforced elements.

Since March 1992 Ringvaart has been operating a production system involving the latest developments in the fields of technology and automation to make elements for the precast concrete industry.

Halfway through 1990 the decision was taken to go ahead with the design and manufacture. Working from a specification covering the overall requirements and price, the firm of Grimbergen in Alphen aan den Rijn designed a system, which was then built by a joint construction team from Grimbergen and Ringvaart.

The aim of designing this type of system was to optimise the production process so that:

- production capacity is increased
- consistent quality is delivered
- the number of actions involving people is kept to a minimum
- a visually more attractive product can be made
- various sorts of elements can be produced
- the working conditions of staff are improved.

The main products are foundation piles and foundation girders with a maximum length of 12 metres. In addition, other precast concrete elements are produced, such as support blocks, girders, joists, etc.

The standard type of concrete used is B55 quality. The production process for the elements has been certified in accordance with the KOMO/KIWA standards which apply in the Netherlands.

In the start-up phase (approx. 10 months), elements with traditional reinforcement are being produced. After the start-up phase the process will be modified for future use, by fixing an auxiliary structure on top of the formwork so that elements can also be made with pre-stressed reinforcement.

The design provides for such a modification to be made.
The system is based on the principle of a stationary filling station and a rotating formwork system. The maximum standard mould size is 12 m long, 1.30 m wide and 0.6 m high.

The rotation process with the PLC driven portal crane is fully automated. At the site of the various stations, the formwork can be semi-automatically inserted into the rotation process and removed. Before the production day starts, a disc is fed into the system with details of the type of production required.

The priorities are set beforehand and based on these, the portal crane positions itself at the selected locations, ready for rotation of the formwork being handled that day. The positions of the moulds are moved not only by the portal crane but also by means of a horizontal roller system. Each position is provided with motion sensors so that the central program can also register these movements. This system of moving the moulds operates semi-automatically, as mentioned above. In order to carry out a task, the command has to be given manually. This working method is used wherever people may need to control the length of time at a certain position, for example when building in mesh and emptying the formwork.

Each of these positions for moving the formwork is provided with motion sensors and recording sensors, so that the formwork positions can be registered by the main system. Because of this, the main system will allow the portal crane to continue processing moves which are controlled by external commands, as well as carrying out the fully automated moves.

The rotation process consists of different stations:

- a parking position, unique to each formwork
- the station for building in mesh, with 2 possible positions, depending on the progress of this work
- the filling station position with parking facilities for several moulds.
- the repositioning position with parking facilities
- the hardening positions of the various moulds
- the emptying station
- the cleaning station
Production data is entered for the formwork type and sequence, and this determines the way the moulds are moved around by the portal crane.

Before the production day begins, the system starts up automatically in the early morning, in order to move the moulds filled the previous day from the hardening positions to the emptying station.

Each formwork has its own machine-readable code and each position has a registration code. Throughout the movements, the system continues to register the new position data from the various moulds. Based on the priority data, the movements are carried out independently by the system, ensuring the optimum efficiency of the (unmanned) crane movements.

All activities are registered, using an on-line connection (via a modem) to a mainframe in Germany. In the event of any malfunction, the situation can immediately be assessed here and corrected if necessary.

As a result, loss of production is kept to a minimum.

The supply of mortar from the concrete plant takes place by monorail using a special transport container, which can be regulated to run continuously or on demand. The movements of the transport container are semi-automatic.

The supply of mortar for each loading is 2 m³. The formwork to be filled is fixed onto a base by means of a vacuum system, with vibrators mounted underneath for compacting the mortar. During the filling process, the person in charge of filling can regulate the frequency of the vibrations to obtain the best compaction.

Approx. 24 hours after the formwork is filled, the element is released. The initial strength is then approx. 35 N/mm², which is more than sufficient for it to be moved to the stacking area. The elements are released by first opening the formwork a few millimetres on a base, then vacuum lifting the elements out of the formwork using a suction attachment and placing them on a transport vehicle.

In principle the elements are left in the stacking area for at least 14 days to allow strengthening to occur.
Each element is provided with a code label immediately after the formwork is filled, and the hoisting positions and any special requirements are indicated on the element using a colour code.

The position of the element in the stacking area is recorded in a separate storage program. When the time comes to move the element to the worksite, it is a simple matter to call up the positions of the different elements which need to be transported. From the worksite the dispatch department is notified of the delivery sequence for the elements.

Quality control takes place throughout the production process. Every day test cubes are made and the different properties of the concrete are tested in an internal lab. The mortar is checked and in addition the reinforcement, the settings for the size of elements and any special requirements are subject to spot checks.

Conclusion

The development of this system in collaboration with Grimbergen is a further step towards perfecting the production process for concrete elements, especially through the use of automation techniques.

The market is showing increasing interest in applying this production process to elements which in the past were produced in a more traditional way. In this way automation combined with optimalisation of the associated production processes can open up new segments of the market.
Optimal design and use of industrial building precast prestressed concrete floors and roofs in Russia

L. V. Sasonko
Optimal grade and use of industrial building materials in the construction of houses and houses in Russia

T. N. Yezhako
The paper provides the information on optimal design of several industrial building precast structures which fabrication and use had been recently implemented in Russia: floor and roof slabs 3x12m sized with longitudinal ribs of variable depth, two-slope roof beams with prestressing bars bent up, lattice beams of variable depth for 12 and 18m spans, 24m span roof trusses with brace prestressing bars bent up, 12m span trussed girders, prestressed span-size roof slabs of "T" type 3x18m and 3x24m and roof blocks made of such slabs as well as span-size slabs 3x18m with lattice girder longitudinal ribs.
Precast prestressed concrete ribbed slabs 3x12m of constant height, line reinforced have been widely applied as floor and roof slabs of industrial buildings in Russia. Recently the optimization of such slab structure was conducted. Longitudinal ribs outline became variable with rib height decreasing from the middle of the span to the support, all prestressing reinforcement bent up. For such slabs fabrication the available force moulds have been modernized. Due to slab size changes of slab leading to transversal and longitudinal reinforcement reduction, the consumption of concrete and steel as well as half-finished product cost and labor requirement and reinforcement prestressing decreased by 10-20 per cent against constant height slabs with linear reinforcement.

Fig.1 Beam optimal design conditions (based on normal crosssection strength)

a - one twisting point over half-span; b - the same, at the middle of the span; c - two twisting points over half-span
The optimal design's condition is the determination of reinforcement bend point and cross-section height alteration points to obtain the minimum difference between epure areas of outer moments and moments of bearing capacity. Fig.1 illustrates the approximate calculations by diagram analytic method accounting only for the strength of normal longitudinal cross-section.

Considering the solution in case of even distributed loading and one point-twisting at the middle of the span middle (Fig.1a) and taking \( \frac{b_1}{f} = \xi \), we determine the relative location of twist point in the span as

\[
\frac{e_{om}}{c} = \frac{1 - \xi}{4(1 - \sqrt{\xi})}
\]  

(1)

On the base of the formula we have drawn up a diagram (Fig.2, curve 1) using which one can determine twist point maximum distance from the support \( (l_{om}) \) when \( \xi \) is known.

The most effect from concrete requirement reducing and the least expenses for bent-up reinforcement prestressing are reached in structures with single reinforcement twisting point placed at a position of maximum outer force moments epure ordinate (at the middle of the span, for symmetrical loading, Fig.1b). In this case one has to increase the reinforcement but nevertheless the variant with single twist point at the middle of the span is to be considered when choosing the optimal beam structure.

Let coefficient \( K \) be the ratio of the moment at the middle of the
span to the maximum ordinate of parabola. Then

\[ \frac{f}{k} = \frac{M_{\text{max}}}{M_{\text{np}}} = k = 2 - 2 \sqrt{\frac{\xi}{g}} + \frac{\xi}{g} \]  

(2)

Fig. 2 shows coefficient \( K \) versus \( \xi \) values.

When determining final variant the economical comparison was conducted. The rapprochement of bearing capacity moments epures to those of outer forces may be continued by increasing the number of twist points. But practice of with bent-up reinforcement structures design and fabrication show that the number of twist points for half-span being more than two the arising of considerable complication of structure fabrication technology can not be compensated by material requirement reducing.

The diagrams allow to choose quickly the rational outline and reinforcement layout of bended elements with bent up reinforcement. It is quite difficult to get the optimal analytic solution accounting for all limit states. This problem was solved using computer.

The analyses were aimed to find a structural design with minimum cutting requirement providing the necessary strength and crack resistance during all working stages. Analyses program envisaged varying of reinforcement type, concrete class, the distance from beginning to butt-end of the slab, bending up angle and reinforcement disposition along crosssection depth at the middle of the span.

Fig. 3 Beam manufacturing at the long stand

1 - diaphragms; 2- fixing pins; 3- bent up reinforcement

The optimization methods checked on slab structures were transmitted on roof beam structures. In prestressed two-slope beams for 12 and 18m
spans, a part of longitudinal prestressed reinforcement bars were bent up to higher zones of support cross-sections, what provided the 10 percent steel saving compared to the beams with linear reinforcement. Such beam were fabricated using a long stand. To maintain the planned layout of prestressed reinforcement diaphragms were applied between beams and fixing pins (Fig.3).

The optimization analysis program was also used for 12 and 18m span lattice beams with cutting in support zones and bending up all reinforcement bars. To decrease material requirements in such structures the random search method was used in computer program. Unknown geometrical dimensions — the length and the depth of bar bending up projection, dimensions of lattice element cross-sections (Fig.4) — were considered as control parameters. These parameters' combination was determined by random number generator.

Fig.4 Beams with bent up reinforcement (dimensions in cm)

a - 12m span; b - 18m span (in parentheses - values for type 11)

The concrete requirement of the structure was accepted as a goal function. The minimum value of the function was found by a program learning during design process. For this the whole search process was divided into 4 stages each of which terminates when a certain number (up to 25) of beam variants successfully passing all checks is accumulated. Parameters values of the best variant in relation to the concrete requirement, obtained on previous stage, was considered the dispersion center on the current stage. After control parameters raffling the checking calculations for this variant were conducted.

So structure parameters were arranged in following order: the first was the concrete requirement, the second was the requirement of prestressed
reinforcement, and strength characteristics of the concrete were the third. The materials costs were considered only when making final selection of variants. The study has resulted in 10-15% reduction of material costs.

Mastered methods of prestressed bars bending up were applied to fabrication of 24m span trusses with brace bent up prestressed bars (Fig. 5). This allowed to save 40% of concrete and 10% of steel against standard trusses and to ensure braces crack resistance.

Fig. 5 Layout of prestressed reinforcement in the 24m span girder

The trusses were fabricated in stand-moulds envisaging group prestressing. Bent up bars were fixed in twist points by special pins with anti-friction devices [1].

Fig. 6 12m span trussed girder with bent up reinforcement
A similar method was used when designing and applying 12m span trussed girders with prestressed bars bent up. Besides of materials saving the mentioned method has allowed to give up temporary erecting-stage connections because gravity center of such girders is below bearing point (Fig.6).

On the base of optimization analyses large size slabs (3x18 and 3x24m span) were developed. One of possibilities of effective application of such slabs is their assembling in enlarged three-dimensional 6x18 and 6x24m blocks disposed when erecting directly on columns without longitudinal truss structures. This allows to reduce labor requirement when erecting and to reduce material consumption of the structure (Fig.7) [2].

To unite the slabs into a block, in their butt-end ribs which depth is to correspond support crosssection depth of longitudinal ribs, the channels are arranged by the use of inserts, then the reinforcement is drawn through the channels and tensioned. It is possible to unite slabs by tensioning higher and lower bars and welding inserts on the top of joint between slabs. When loaded such a block behaves as a three-dimensional system in which all ribs experience the transversal bending and twisting torsion.

The block deformation is determined by linear dislocation functions of edge \( W_k(x) \), middle \( W_c(x) \) and butt-end \( \nu(y) \) ribs and also by their angular dislocation functions \( \varphi_k(x) \), \( \psi_c(x) \) and \( \theta(x) \) respectively. Along the contact between flange and edge ribs the internal shear forces
$q_k(x)$ and transversal moments $m_k(x)$ act. for middle ribs $q_k(x), m_c(x)$ respectively. The transversal forces $Q_k, Q_c$ torsion $M_k$ and bending $M_T$ moments as well as support reaction forces $R$ are transmitted on butt-end ribs from transversal ribs.

Block loading is formed of the loading distributed on its surface $P(x,y)$ and the loading $q_k(x)$ applied on edge and middle ribs with eccentricities $e_k(x)$ and $e_q(x)$. To make the calculation more compact the loading is divided into symmetrical and inverse symmetrical parts relative to $OX$ axe passing through the joint between slabs. Dislocations and forces distribution are shown on Fig.8.

**Fig.8** Displacements and efforts in the block under uniformly distributed load

a - symmetrical; b - inverse symmetrical

To solve the problem the functions of outer and inner forces and
dislocations as well as the $U_c, \gamma_k, Q_c, M_k, M_T$ values are expanded in trigonometrical series, then the parameters $\overline{\eta}_i, \overline{\eta}_{ki}, \eta_{ci}$ are determined accordingly to the distribution of these functions in $X$ direction. Other parameters are determined by calculation.

To determine the trigonometric expansion parameters let us present the unknown forces through the rib dislocation values, and then express the rib dislocations resulting from outer loading and inner forces through the dislocations to be found.

Tables 1 and 3 contain equations relating forces and rib dislocations for symmetrical and inverse symmetrical type of the loading and Tables 2, 4 show the final equation systems to find values of dislocations.

In Tables 1-4 the following is accepted:

$$K_1 = 1 + 2\lambda; \quad K_2 = 1 + 5.5\lambda; \quad K_3 = 1 + 3\lambda;$$

$$K_4 = 1 + 6\lambda; \quad \lambda = \frac{E_2}{E_1}; \quad \lambda_1 = \frac{E_3}{E_2};$$

$$K_5 = \frac{1}{12} \cdot \frac{B_1}{E_2 E_2} \cdot \left(\frac{i X E_2}{E_1}\right)^4; \quad K_6 = \frac{1}{3} \cdot \frac{B_{xx}}{E_2 E_2} \cdot \left(\frac{i X E_2}{E_1}\right)^2;$$

$$K_7 = \frac{1}{48} \cdot \frac{B_{xx}}{E_2 E_2} \cdot \left(\frac{i X E_2}{E_1}\right)^5; \quad K_8 = \frac{1}{4} \cdot \frac{B_{xx}}{E_2 E_2} \cdot \frac{E_3}{E_1} \cdot \frac{i X E_2}{E_1};$$

where $B_1$ is the rigidity of a longitudinal rib in case of plane bending accounting for adjoining flange zone; $B_2$ - the rigidity of flange stripe (of the unite width) in case of transversal bending, $B_T$ - the rigidity of butt-end rib in case of plane bending, $B_{kp}$ and $B_{kp,T}$ - the rigidities of longitudinal and butt-end ribs in case of twisting.

In practice first the systems of equations from Tables 2, 4 are solved for $i=1$, then the found dislocations are substituted in systems of equations (Tables 1, 3) from which unknown forces are determined. Then the calculations for following $i$ values are made. The process is finished when revision due to the next member becomes negligible.

The analyses show that the application of three-dimensional 6x18m sized blocks instead of two 3x18m slabs with longitudinal beams allows to reduce material and labor requirement of 10%.

3x18 and 3x24m sized slabs with lattice girder longitudinal ribs (Fig. 9) are an other type of span-size slabs. These slabs allow the engineering communications to be arranged within the roof depth, the building ventilation effectiveness and its natural illumination being improved.
<table>
<thead>
<tr>
<th>Factor</th>
<th>Equation</th>
<th>$\bar{w}_{ki}$</th>
<th>$\bar{w}_{ci}$</th>
<th>$0.5 \bar{L}<em>2 \bar{v}</em>{ri}$</th>
<th>$0.5 \bar{L}<em>2 \bar{v}</em>{ci}$</th>
<th>$\bar{v}_{ci}$</th>
<th>$0.5 \bar{L}<em>2 \bar{v}</em>{ki}$</th>
<th>$0.5 \bar{L}_2 \bar{P}_i$</th>
<th>$\bar{V}_{ki}$</th>
<th>$\bar{V}_{ci}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>$\frac{\bar{L}^3}{12 \bar{B}<em>2} \bar{V}</em>{ki}$</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>$+ \frac{4}{i \bar{x}}$</td>
<td>$- \frac{4}{i \bar{x}}$</td>
<td>$\bar{L}^3_2$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$b$</td>
<td>$\frac{\bar{L}^3}{12 \bar{B}<em>2} \bar{V}</em>{ci}$</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>$- \frac{4}{i \bar{x}}$</td>
<td>$+ \frac{4}{i \bar{x}}$</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$c$</td>
<td>$\frac{\bar{L}^3}{6 \bar{B}_2} (\bar{M}<em>r + \bar{V}</em>{ki} \cdot \bar{e}_q)$</td>
<td>$- k_1 + k_1 - \frac{4}{3} k_2 + \frac{4}{3} k_3 + k_1$</td>
<td>$\bar{V}_{ci}$</td>
<td>$- \frac{4}{i \bar{x}}$</td>
<td>$\frac{4}{i \bar{x}}$</td>
<td>$\frac{\bar{L}^3_2}{36 \bar{B}_2}$</td>
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<td></td>
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<tr>
<td>$d$</td>
<td>$\bar{M}<em>c + \bar{V}</em>{ci} \cdot \bar{e}_q$</td>
<td>$- k_1 - k_1 + \frac{4}{3} k_3$</td>
<td>$\bar{V}_{ci}$</td>
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<tr>
<td>$e$</td>
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<td>-1</td>
<td>+1</td>
<td>-1</td>
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<td>$k_1$</td>
<td>$\frac{4}{i \bar{x}}$</td>
<td>$\frac{4}{i \bar{x}}$</td>
<td>$\frac{\bar{L}^3_2}{36 \bar{B}_2}$</td>
<td>$k_p \bar{L}_2$</td>
</tr>
<tr>
<td>$g$</td>
<td>$\frac{i \bar{x}}{\bar{L}_2} \cdot \frac{\bar{L}^3}{\bar{B}_2 \bar{r}} \bar{M}_r$</td>
<td>-1</td>
<td>+1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Factor</td>
<td>$\overline{W_{ki}}$</td>
<td>$\overline{W_{ci}}$</td>
<td>$0.5 \ell_2 \overline{y_{ki}}$</td>
<td>$0.5 \ell_2 \overline{y_{ci}}$</td>
<td>$0.5 \ell_2 \overline{v_{ki}}$</td>
<td>$0.5 \ell_2 \overline{v_{ci}}$</td>
<td>$\frac{P_i \ell_i^4}{24 B_x}$</td>
<td>$\frac{f_{ki} \ell_i^3}{12 B_x}$</td>
<td>$\frac{f_{ci} \ell_i^3}{12 B_x}$</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>----------------------</td>
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<td>-------------------------------</td>
<td>-------------------------------</td>
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<td>-------------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td>$1+K_1+K_0$</td>
<td>$-(1+K_0)$</td>
<td>$+1$</td>
<td>$-1$</td>
<td>$-\frac{4}{i\ell}$</td>
<td>$+\frac{4}{i\ell}$</td>
<td>$+1$</td>
<td>$+1$</td>
<td>$0$</td>
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</tr>
<tr>
<td>$b$</td>
<td>$1+K_0$</td>
<td>$1+K_1+K_0$</td>
<td>$-1$</td>
<td>$+1$</td>
<td>$+\frac{4}{i\ell}$</td>
<td>$-\frac{4}{i\ell}$</td>
<td>$+1$</td>
<td>$0$</td>
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<td>$c$</td>
<td>$+k_1$</td>
<td>$-k_1$</td>
<td>$\frac{K_0 + 4}{3} k_2$</td>
<td>$-\frac{2}{3} k_3$</td>
<td>$-k_4$</td>
<td>$\frac{4}{i\ell} k_2 \cdot \frac{4}{i\ell}$</td>
<td>$+\frac{1}{3}$</td>
<td>$+2k_2$</td>
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<td>$d$</td>
<td>$-k_4$</td>
<td>$+k_4$</td>
<td>$-\frac{3}{2} k_3$</td>
<td>$\frac{4}{i\ell} k_2$</td>
<td>$-\frac{2}{3} k_3 \cdot \frac{4}{i\ell}$</td>
<td>$+\frac{1}{3}$</td>
<td>$0$</td>
<td>$+2k_2$</td>
<td>$+k_3$</td>
<td></td>
</tr>
<tr>
<td>$e$</td>
<td>$-\lambda$</td>
<td>$+\lambda$</td>
<td>$\frac{1}{3} - \lambda$</td>
<td>$\frac{1}{3} k_3$</td>
<td>$\lambda$</td>
<td>$\frac{4}{i\ell}$</td>
<td>$K_0 + \frac{4}{i\ell} k_2 \cdot \frac{4}{i\ell}$</td>
<td>$+\frac{1}{3}$</td>
<td>$+2k_2$</td>
<td>$+k_3$</td>
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### Table 3

<table>
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<tr>
<th>Equation</th>
<th>$\bar{W}_{ki}$</th>
<th>$0.5\ell_2\bar{y}_{ki}$</th>
<th>$0.5\ell_2\bar{y}_{kl}$</th>
<th>$0.5\ell_2\bar{P}_i$</th>
<th>$\bar{q}_{ki}$</th>
</tr>
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<tr>
<td>$\frac{\ell_2^3}{12B_2}\bar{q}_{ki}$</td>
<td>-1</td>
<td>-1</td>
<td>$-\frac{4}{i\Delta}$</td>
<td>+1</td>
<td>0</td>
</tr>
<tr>
<td>$\frac{\ell_2^2}{6B_2}(\bar{m}<em>{ki}+\bar{q}</em>{ki}+\bar{q})$</td>
<td>$-k_1$</td>
<td>$-\frac{4}{3}k_2$</td>
<td>$-\frac{4}{3}k_2\frac{4}{i\Delta}$</td>
<td>$\frac{l_2^3}{36B_2}k_p$</td>
<td>$-\frac{l_2^3}{6B_2}\lambda g$</td>
</tr>
<tr>
<td>$\frac{1\Delta}{\ell_1}\frac{\ell_2}{6B_2}\bar{M}_{ki}$</td>
<td>$-k_1$</td>
<td>$-\frac{4}{3}k_2$</td>
<td>$-\frac{4}{3}k_2\frac{4}{i\Delta}$</td>
<td>$\frac{l_2^3}{36B_2}k_p$</td>
<td>$\frac{l_2^3}{6B_2}\lambda g$</td>
</tr>
<tr>
<td>$\frac{\ell_2}{B_{kpT}}\frac{\ell_2}{1\Delta}\bar{M}_{ti}$</td>
<td>+1</td>
<td>0</td>
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</table>

### Table 4

<table>
<thead>
<tr>
<th>$\bar{W}_{ki}$</th>
<th>$0.5\ell_2\bar{y}_{ki}$</th>
<th>$0.5\ell_2\bar{y}_{kl}$</th>
<th>$\bar{P}_i \cdot \frac{l_2^4}{24B_2}$</th>
<th>$\bar{q}_{ki} \frac{l_2^3}{12B_2}$</th>
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</thead>
<tbody>
<tr>
<td>$1+K_i+K_{ij}$</td>
<td>+1</td>
<td>+</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>$+k_1$</td>
<td>$K_{ii}+\frac{4}{3}k_2$</td>
<td>$\frac{4}{3}k_2\frac{4}{i\Delta}$</td>
<td>$+\frac{1}{3}$</td>
<td>$+2\lambda g$</td>
</tr>
<tr>
<td>$+k_1$</td>
<td>$+\frac{4}{3}k_2$</td>
<td>$K_{j}\frac{8k_2^3}{3}+16k_2\frac{3}{i\Delta}$</td>
<td>$+\frac{1}{3}k_p$</td>
<td>$+2\lambda g$</td>
</tr>
</tbody>
</table>
To analyze the stressed-deformed slab state the computer program "Lira" was used for different charging schemes in limit direction[3]. The problem was solved for plane case assuming the real transversal crosssection to be T-shaped. In the analysis scheme the slab was divided into finite elements — bars and triangular webs.

Fig. 9 Computer-aided slab analysis
a — geometrical layout and crosssections of slab elements; b — design scheme of the slab; c — loading pattern and slab fixing conditions

The behavior analysis in case of standard loading was aimed to determine slab deflection and forces in its elements for further estimation of crack resistance and crack opening width. In addition to
the outer loading the forces of reinforcement prestressing were accounted for experienced in form of horizontal and vertical components of central pressure forces on each of slab butt-ends. The central pressure force was determined accounting for total losses of prestressing.

The analysis scheme allowed hinges in the lower slab zone the preliminary analysis having showed cracks opening in the lower zone in case of standard loading. The lower zone elements (7-9, 9-11, 11-13, 13-15) were assumed to be finite bars with axial rigidity \( \frac{E_5 A_5}{\psi_5} \) where \( \psi_5 \) is assumed equal to 0.9.

The analysis of the case of design loading was aimed to determine efforts in slab elements for further estimation of their bearing capacity. central pressure force not being accounted for assuming its total compensation.

The slab analysis in transversal direction is more difficult, involving the estimation of longitudinal ribs twisting angles and calculation of their twisting moments, as well as support and span bending moments in transversal ribs. On the base of the analysis an U-shaped net is disposed in support zone of transversal ribs to suspect twisting. the longitudinal and transversal reinforcement of transversal ribs is determined. the crack resistance of assumed longitudinal ribs' crosssection is checked.

The grade of top slab plane being negligible (i=1:100), the turn angles and twisting moments in transversal ribs as well as transversal forces in transversal ribs were determined without accounting for compressing efforts in the flange.

The system of equations to calculate the moments \( M_{kp}(i) \) is presented in Table 5, where

\[
t_{ik} = \frac{2B_2(i) K_1(i) (k) }{B_{kp}(k)} \frac{\psi_n}{\psi_a}
\]

here \( B_2(i), B_{kp}(k) \) are the rigidity of \( i \)-th transversal rib without cracks in case of twisting and of \( k \)-th zone of longitudinal rib in case of twisting, respectively; \( K_1(i), K_2(i) \) are the coefficients accounting for moment redistribution in \( i \)-th transversal rib after cracks arising; \( \psi_n, \psi_a \) slab flange sizes within the limits of one caisson.

Parameters' indexes are accepted according to Fig.10.

The twisting rigidity of different longitudinal rib zones was determined by a formula
<table>
<thead>
<tr>
<th>Number of section</th>
<th>$0.5 M_0$</th>
<th>$M_1$</th>
<th>$M_2$</th>
<th>$\frac{q E_n l_2^2}{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$2 + t_{00} + t_{01} + t_{02}$</td>
<td>$t_{01} + t_{02}$</td>
<td>$t_{02}$</td>
<td>$K_1 (0) \lambda_0$</td>
</tr>
<tr>
<td>1</td>
<td>$t_{11} + t_{12}$</td>
<td>$1 + t_{11} + t_{12}$</td>
<td>$t_{12}$</td>
<td>$K_1 (1) \lambda_1$</td>
</tr>
<tr>
<td>2</td>
<td>$t_{22}$</td>
<td>$t_{22}$</td>
<td>$1 + t_{22}$</td>
<td>$K_1 (2) \lambda_2$</td>
</tr>
</tbody>
</table>
The twisting rigidity of higher and lower zones respectively; \( B^H \), \( B^L \) - the same in case of horizontal bending; \( z \) - the distance between gravity centers of higher and lower zones.

For longitudinal rib zone without cracks (the higher zone and walls in near supports) the rigidity \( B_{kp} \) was calculated as

\[
B_{kp} = 0.45 E \varepsilon_y g_{kp}
\]

and for zones with cracks (lower zones) it was accepted equal to \( 0.25 B_{kp} \).

**Fig. 10 Calculation of turn angles and twisting moments in longitudinal ribs of the slab**

The turn angles in transversal ribs cross-sections were determined by the following formula

\[
\varphi = 0.5 M_0 \ell_0 \left( \frac{1}{B^H_{kp}} + \frac{1}{B^L_{kp}} + \cdots \right) + M_1 \ell_1 \left( \frac{1}{B^H_{kp}} + \frac{1}{B^L_{kp}} + \cdots \right) + \cdots
\]

Analysis of sloped section rigidity and crack resistance was conducted for joint action of transversal forces and twisting moments.

The transversal ribs were considered as beams elastically fixed at the ends and trapeziformly loaded with maximum loading intensiveness \( \varphi \ell_n \).

The total support bending moment in transversal rib accounting for support section turn due to longitudinal rib twisting is determined so

\[
M_{on}(i) = \frac{4 \varphi \ell_n \ell_2^2 K_1}{12} - \frac{2 B_1}{\varepsilon_2} \cdot K_2 \cdot \varphi(i)
\]

and span bending moments are

\[
M_{np}(i) = \frac{4 \varphi \ell_n \ell_2^2}{8} \cdot \left( 1 - \frac{2 B_1}{\varepsilon_2} \right) - M_{on}(i)
\]
The maximum of transversal force is equal to

\[ Q = 0.5 \eta n \frac{L_n}{l_2} k_{n e} \]  \hspace{1cm} (8)

where \( k_{n e} = 1 - \frac{\gamma_n}{\eta_n} \), \( \eta_n = 0.5 \frac{L_n}{l_2} \)

The optimal structure design was conducted together with their fabrication implementation and the testing of control samples which allowed to prove the soundness of the accepted analysis schemes.

REFERENCES
1. SASONKO L. Fabrication of prestressed structures with bent up reinforcement at precast concrete plants; VNIITESTROM, Moscow, 1978.
\[ a, b, c, d = 0 \]

\[ a^2 + b^2 + c^2 + d^2 = r^2 \]

...
How to manage the process

H.W. Bennenk
How to manage the disease

W. Bennett
HOW TO MANAGE THE PROCESS.

1.0 INTRODUCTION.
Future developments in the precast-industry are depending on many aspects. In this paper several of these aspects will be discussed, **logistics and automation** are important items nowadays, but I will try to pay attention to **future challenges** as well, reviewing the total process and the range of products, manufactured within this industry.

The precast-concrete business is not easy to compare with other businesses. The companies are quite different structured and equipped, depending on the type of product and the customers role. The customer as buyer or client. One can distinguish large serie- or massproducts like f.i. tiles, tubes, paving bricks, manufactured automatically, and unique or low serie products, mostly used in structures, specified by the client and manufactured in a not specific automatised environment.

In some companies we find a mix of those products in the product range. The differences between precast-companies, manufacturing large serie and those supplying unique elements on clients specification, custom or tailor made, will be elucidated.

2.0 THE PRODUCTION OF LARGE SERIES.
The companies, specialised in a short range of products and producing thousands of each annually, have invested heavily in the last decades. The total manufacturing process is automated now to a high extent or completely from the supply of basic materials until storage of the ready product and the provisions required for transport.

For operation of most machines in production 1 or 2 people are required. High investment-costs versus low labour-costs per product. Sales on direct order or from the available stock.
Logistics directed to the constant availability of the required basic materials, an optimal processflow within production and internal transport and a minimized stock. Concrete bricks, roof tiles etc are mostly supplied to builder's merchants, taking over further commercial activities. The company's success is related to the capability to keep the right balance between stock and market demand. The planning of production, stock, sales and transport can be computerized rather easily. In this branch of the precast-concrete production there are rather high noise levels at the workstations, but not exceptional compared with those during production in other facilities of the precast-industry. Noise levels, recently recorded, have a magnitude between more than 90 and 100 dB(A) when the equipment is not insulated and when insulated still always between 85 and 95 dB(A), see fig [1]. In the next years great efforts are required to improve the quality of the work environment as a whole. Although it will be costly, it cannot be reflected from a social point of view. This point will also be discussed later on.

3.0 THE PRODUCTION OF SMALL SERIES.

3.1 process data.
Planning is extremely important for companies manufacturing small series. The timeschedule starting at the day the order is signed until the last on site activities has to build up as soon as any data are available. It has to be updated continuously and controlled. The total processflow of required data can be described and subdivided as follows:
- 13 measurements
noise level (1/1 octave) (dB)

fig. 1: Concrete brick and
tile production
(uncovered machines)

- 50 measurements
noise level (1/1 octave) (dB)

fig. 3: Floorslab and pile production
mould vibrators

- 7 measurements
noise level (1/1 octave) (dB)

fig. 2: Concrete brick and
tile production
(covered machines)
3.1.1. **building up a file.**

relevant information from the contract:
- bill of quantities,
- quality specifications,
- supply schedule,
- budgets.

3.1.2. **engineering.**

Workingschedule per item to follow up
in cooperation with architects, etc.
until approval for:

- plandrawings,
- details,
- stress analyses,
- inserts etc.,
- elementdrawings,
- shopdrawings,
- finishing,
- surface materials,
- erection plan,
- material specifications,
- materials to be supplied.

3.1.3. **establishing data:**

final elementlist,
date for transport,
quality plan.
3.1.4. work preparation, planning.

In general terms:
- Time schedules, departments,
- Personnel planning,
- Planning means, locations,
- Budgets.

Per activity/department,

a. Moulds,
   - Number of moulds,
   - Marks per model,
   - Transformations,
   - MH required.

b. Reinforcement,
   - Capacity estimation.
   - Indoor/outdoor,
   - Personnel.

c. Purchasing,
   - Materials not in stock,
   - Special aggregates,
   - Natural stone, tiles, ...
   - Dates of deliveries.

d. Deliveries,
   - Materials supplies by client,
   - Cutting, sawing, etc.

e. Production,
   - Changes in equipment,
   - Provisions, method,
   - Locations,
   - Finishing,
   - Q.C. items,
   - Personnel.

f. Stockyard,
   - Location,
   - Stockframes,
   - Hoisting, lifting equipment,
   - Personnel.

g. Transport,
   - Type of car,
   - Frames, changes,
   - Permissions,
   - Loading sequence,
   - Element spec./car,

h. Erection on site,
   - Erection materials,
   - Stockprovisions,
   - Equipment etc,
   - Team.
   - On site facilities.
3.2 PLANNING AND PROCESS CONTROL.

It is obvious, that the complexity of the process, the logistic and planning, strongly is depending on type of the elements and the size of the project. Every stage of the process has to be examined for every project whatever the size of the project will be.

Another fact is that railwaysleepers, prestressed structural elements, floor elements, reinforced elements, architectonical concrete, have to be handled in a different way because of the required equipment and the production location, hall. That's why those product groups have to be planned in a different way as will amplified later on.

Although the planning for one project can be extensive and complex, one has to combine all separate plannings to achieve an overview.

It is absolutely necessary to aim for a loading as equal as possible per department, per factory.

So we need several planning modules with different options.

a. On company-level: the management info has to be complete but condensed; a comparison between capacity, loading and budgets.

b. On plant-level: capacity against loading, personnel, material demands on the long and midterm run.

c. On department-level the sequences, loading versus capacity.

d. On project-level all internal and external actions and relationships between those presented in the timeschedule.
The quantity and the quality of project-related data increase according to the progress in engineering.

By using the most detailed information for every item, the most reliable figures and schedules are available at any moment.

A complete system, like explained before, has been developed within Schokbeton and is in use. Examples of output give you an impression of the data available at every level; for the management but also for the supervisor on the floor.

For extended projects with low serie-coefficients and more than one erection stage, it may be very complicated to trace the right production sequence and to keep this sequence to the minute. But for a project containing 2500 elements from which 2000 have different identities, marks, and furthermore considering that the final information is available according to the progress of engineering and knowing by experience that the erection following order and stages change more than once, the task of a planning engineer is quite hopeless and very timeconsuming.

That's why we have build separate planning-modules based on the network principles for different productgroups.

The planning module for reinforced concrete elements is valid for the planning of f.i. extended facades.

The approach is as follows: In the first stage of the project a lot of the supplied data is preliminary. Nevertheless the best possible elementlist is disposed and forms the basis for a rough estimation of the number of moulds and the sequence. It will be explained by an example.

Element nr. D 24, will be produced in mould D, after element D 23 and before D 25.
The time required to transform the mould from D 23 into D 24 is related to element D 23 etc. Within the programm is defined how many manhours of transformation can be done, followed up by casting still the same day or the next or later. When a longer hardening period than 12 or 14 hours is required or other activities have to be carried out, it is taken into account. The same procedure is valid in cases of separated castings and assembling. The element has to be provided with the date of transport or the date available for erection on site. It is the choice of the planning engineer to let start the planning at date zero and to let check the elements availability at the required dates or to let start the planning from the moment the element has to be ready. Depending on the answers, one can change and rerun the program.

One can imagine that a similar planning module has been build for elements produced on long lines, with several different elements in one mould, one for the caroussel and another for floor elements. Because the availability of an element has to be priority number 1, all actions have to be pointed to manage that.

Daily practice shows, that not always the approved drawings are available in time, a logical result of the involvement of a lot of partners in the preparation process of a project and not seldom a to hasty start or late decisions. Last minutes changes are disturbing the progress once more. But it cannot be denied that in many projects time is lost because of external facts. The last solution or possibility is to shorten the internal leadtimes and in extreme situations, to make additional moulds or cast twice a day. The date of delivery will seldom be changed because of the reasons mentioned before. That privilege is the clients one. So anyhow, planning tools and discipline to follow up the schedules is a main tool for a precaster to be a reliable partner in the building process. But there are other tools as well.
3.3 CAD-CAE-process data -CAM.
How the availability of process data has been organised technically, has not yet been discussed. It is obvious, that all capacity- and planning data are handled by computer. It is a part of the total business-package of the company, containing also project management, stock, purchasing, transport, financing and administration.
The most universal item in this industry is an element. The total business-package is created around an element or the collection of elements. That's why it is possible to create an input based on elements and the related services assembled projectwise or and product groupwise. This strategic decision is that important, because the input is one on element level, so the input can be arranged by the use of CAD, combined with CAE. All relevant data, build up in CAD per element, are directly available as input for f.i. planning- and cost calculation modules. The most reliable information is directly available, by any change.
The level on which CAD operates is not important as long as the required data are created. The next step, from CAD towards CAM or CIM is a very interesting one.

3.4 CAM AND THE RATE OF AUTOMATION WITHIN THE PRODUCTION.
Let us start with a question. Is it possible to use the data build up within CAD as steering data for equipment, machinery?
The answer to this question is in principle positive.
It is possible, but hardly in use in general in the branch of the precast- concrete industry dealing with tailor-made products.
Looking to the production of floorelements, one may say that it operational to a certain extent. To mark slab dimensions, to position recesses or holes, to suggest the holes, to saw the slabs is not new anymore.
Developments in the production of floorelements are moving into a direction of full automation, monitored and operated by some employees.
But not yet tomorrow, it will take another 5 until 10 years. For the production of other structural elements like, walls, columns or beams, one has to find, that the rate of automation is rather low or absent. For reinforcement the coupling CAD-CAM is, in principle, available. The first step is the bendinglist. Second step is the use of these data as input for a cutting-bending machine, sometimes followed up by a selection procedure to combine identical bars from the total filecontent to optimize the operations. The development within companies supplying prefab reinforcements for on site concrete has been a positive impulse in this field. The next step is the assembling of the separate bars to make a complete mesh for f.i. for a column or beam. As far is known one application for wall-elements is in operation. For the automated production of moulds the actual situation is not that different. A robottool, instructed directly by CAD-data, is digging contrashapes in a basic material to get a mould for casting. An effective and economical application is up till now restricted to the more complex shapes. Further developments will show more possibilities. It has to be considered how far further automation is desirable and possible. The finishing of fresh and hardened concrete can be done by a robot. Operations have been started. The automation of bricklaying or placing ceramic tiles in the mould is possible, but asks for economical reasons for almost a continuously use.

3.5 POSSIBLE CONCEPTS. Transport of concrete, moulds and reinforcement in combination with flexible (moving) platforms, casting stations, reinforcement-, mouldrobots, automated finishingstations may give an outlook to an automated and integrated factory concept for some products. One condition will be, that the rate of variation in shape should be low, so the rate of automation will strongly depend on the type of product and will not cover a complete range.
It is after this brief review of possibilities, the right moment to make the following statement:

For 'custom-made' products with a low rate of repetition and not very restricted in shape, requiring much engineering and sophisticated planning tools, the rate of automation is and will be very low. However there are enough reasons to put a lot of efforts to go on with developments, as will be explained later on. Developments may be based on the following approaches:

1. The actual situation on the market will not change. The variation in products will be wide, the serie-coefficient rather low. Automation will be directed to the improvements of separate actions, not leading to a total integrated factory concept.

2. New building-concepts or specific products will be offered to the market, existing of components manufactured in an environment with a very high rate of automation.

It seems to be possible to choose a position between those two extremes. The choice has to be made by every company, because a continuation of the today's practice will, besides the market position, probably lead to problems, caused by the lack of labour and/or skilled labour in the several disciplines. The safety, health and environment conditions combined with the rather heavy workloading are not making this branch to the most favourable one for young people. Governments will become or are already very demanding. Changes are inevitable, but will most probably show a stepwise approach. The feasibility is very depending on the recovering of the economics in the main countries, the market developments and the increase of the penetration rate of precast concrete in the construction market. How do we manage to keep things in the right sequence and in balance? A fascinating and very demanding period has started.
It has been published recently, that Obayashi, one of the leading Japanese contractors, starts to build a multistorey building, with a circular plan, by robots inside a tent or dome. Because of the circular shape the rate of repetition is rather high. The dome is adjustable in level. All to the site supplied elements and other building components are lifted, positioned and fixed by robots, directed by computer according to a designed plan of operation. The reason to start this development is the lack of labour, working conditions, reduced noise level on the site and the possibility to operate 24 hours a day.

A very challenging project, trendsetting to the future. The arguments to start this development don’t differ that much of mine used before. It supports my previous mentioned ideas and arguments on the following aspects:

a. The relationship between the rate of repetition and automation.
b. The influence of working conditions and environmental requirements and the availability of enough and skilled labour.
c. Specific economical considerations.

4.0 AN EXAMPLE.

In the first part of this paper, attention has been payed to companies, manufacturing a small range of products but in large numbers each. Schokbeton is one of the companies, involved in both custom made products and in large serie products. The main serie-product is the Dutch railwaysleeper. The development, two years ago, of a new sleeper in relationship with a complete new production concept shows, how has been chosen between the economy and the rate of automation in the total process. It may be obvious, that optimal working-conditions was one of the design criteria for production process and equipment. It is important after all to work with a motivated staff, the companies main capital for still a long period of time, irrespective the presence of a robot as a workmate.
References:
The automatic concrete plant - reality and vision

W. Reymann

Lassen Sie mich nun das "automatische Betonfertigteilwerk" an dieser Stelle definieren.


Die Aufgabe beginnt bei der EDV-gestützten Erstellung der Angebote und endet mit dem fertigen Baukörper in der Rechnungslegung. Einmal erfaßte Daten begleiten das Projekt bis zum Tapeziervorgang. Daß die Automatisierung kein Selbstzweck ist, belegen folgende Zahlen:
18 automatische Elementdecken- und Wandwerke sind seit 1986 entstanden und produzieren zur Zeit jährlich ca. 5 bis 6 Millionen qm. 8 dieser Betreiber planen den Bau ihrer 2. technisch noch höherwertigeren Produktionsstätte binnen kürzester Zeit, 3 davon sind heute bereits in Betrieb. Nichts beweist wohl mehr die Wirtschaftlichkeit, als diese Entwicklung.

Lassen Sie mich nun die wichtigsten Stationen zum heutigen Stand der Technik aufzeigen:


Bild 1 MRP Lösch

Das Vertrauen in die Technik war damals begrenzt, was der Bedienstand mit Sitz zeigt.


Bild 2 Knickarm Roboter Lösch

- 1989 wurde die Mischanlage in das Steuerungskonzept integriert und ein geschlossenes Waschwasser- und Restbeton-Recyclingkonzept aufgenommen.


Was verstehen wir nun 1992 unter dem Begriff des automatischen Betonfertigteilewerkes?


sollen auf eine automatische Produktion abgestimmt sein und die Funktionalität des Fertigteils sichern.

Bei unseren Elementdeckenwerken werden in Arbeitskreisen technische Details und die daraus entstehenden Angebotspositionen entwickelt und stets auf dem aktuellen Stand gehalten.

Die Integration nachfolgender Betriebsbereiche ist bei der Umsetzung eines automatischen Fertigteilwerkes unabdingbar, um die technischen Möglichkeiten wirtschaftlich zu nutzen.

- Angebotsbearbeitung und -verwaltung zur ständigen Marktübersicht
- Auftragsbestandsverwaltung
- CAD-Bearbeitung (Definition des Einzelelementes und der montagegerechten Transporteinheiten)
- Lagerverwaltung der Rohstoffe, Produktionsmittel und Endprodukte
- Fertigungssteuerung mit Leitstandtechnik
- Transport- und Montagesteuerung
- Anbindung an kaufmännische Verwaltung aller vorgenannten Bereiche.

Das Kernstück des automatischen Betonwerkes ist zweifelsohne die Produktionsanlage.

Bild 3 "Hallenansicht" (Schlagmann) mit verkleideter Mischanlage

Sie wird am besten in einem neuen, attraktiv gestalteten Gebäude installiert. Ein neues Gebäude bietet optimale Voraussetzungen, wobei es nur 20 % der gesamten Investitionskosten ausmacht. Es ist planerisch so ausgelegt, daß
eine universelle Nutzung durch die nachfolgende Generation unter anderen Gesichtspunkten möglich ist.

Bild 4  "Hallenansicht (Lösch) mit verkleideter Mischenlage

Weiterhin eröffnet der Neubau die Chance, das vorhandene Gelände infrastrukturell neu zu gliedern. So können auch weitere Investitionsmaßnahmen materialflußgerecht umgesetzt werden.
ausbaufähig für 4 Produktionsbereiche

Bewusst wird das Büro mit in die Überlegungen einbezogen, um auch hier optimale Bedingungen zu schaffen.

Eine moderne Werkskonzeption beinhaltet die Verfügbarkeit der Produktionsmittel- und -stoffe überschaubar in unmittelbarer Nähe der Verwendungsstelle.

Den heutigen Stand der Technik möchte ich anhand eines Beispiels für eine Multifunktionsanlage dokumentieren, beginnend mit den Bereichen Entschalen und Plattenabheben.

Bild 6 (Folie) "Übersicht Multifunktionsanlage"
Die Reihenfolge der zu entschalenden Paletten gibt der Leitrechner nach den Kriterien der montagefreundlichen Transporteinheiten vor.


Bild 7 "Wand mit Kipptisch und Transportgestell"

Die 2. Station ist als Entschalstation für Wände mit Kippvorrichtung ausgebildet. Neben dieser Station steht eine Transportpalette zur Aufnahme der Wände bereit. Alternativ können 2 Deckenstapel auf dem Transportwagen gebildet werden.

Bild 8 "Deckenstapel" = montagefreundlich geordnete Logistikeinheit

Zum Handling der Teile wird ein speieltes Abhebegerät oder der Hallenkran mit 2 Hubwerken eingesetzt.


Die Gitterträger werden ebenfalls von einer computergesteuerten Anlage dem Tagesvorrat entnommen, abgelängt und für den Einlegeroboter bereitgestellt.

Beim Belegen der ersten Lage werden die Stäbe mit Abstandshaltern aufgelegt.

Für die erste Lage sind in der Planung zwei verschiedene Dimensionen Rundstahl und zwei Dimensionen Abstandhalter (15 und 25 mm)vorgesehen.

Die handelsüblichen Gitterträger werden in 14 Meter Längen in einem seitlich angeordneten, in der Höhe verfahrbarer Fächermagazin zwischengelagert. Hier können bis zu 13 verschiedene Trägersorten eingelagert und durch Ansteuerung des entsprechenden Faches bequem von dem Bedienungsmann entnommen und konfektioniert werden. Der Gitterträger wird dabei durch eine hydraulische Schere und gegen einen CAD-gesteuerten Meßanschlag
geschoben und geschnitten. Reststücke können mit einer Stumpfschweißmaschine zusammengeschweißt werden.

In den Stationen 6 und 7 wird manuell die Bewehrung kontrolliert, nachgerichtet und zusätzlich Einbauteile wie Fenster- und Türzargen oder Aufkantungselemente eingebaut. In diesem Bereich ist ein fahrbares Arbeitsplatzsystem neben der Palette eingerichtet.

Bild 11 "automatischer Betonverteiler"

Der automatische Betonverteiler wurde den wachsenden, anspruchsvolleren Aufgaben angepasst. Er ist höhenverstellbar, drehbar und in seinem Austragsverhalten gewichtskontrolliert regelbar. Somit betoniert er kleine, filigrane Teile genauso exakt wie größere Fertigteile.

Die Transport- u. Lagertechnik ist ebenfalls, der anspruchsvolleren Aufgabe entsprechend, angepasst.

Bild 12 "Regalförderfahrzeug"

Durch moderne Zentrallagertechnik ist ein durch den Leitrechner verwalteter, flexibler Zugriff gegeben.

Die Lagerregale werden auch als Schalungslager sowohl für komplett geschalte Paletten als auch für nicht aktuell eingesetzte Schalungsbaubauten-Teile verwendet.

Bild 13 "Entschalgerät"
Zur Herstellung von zweischaligen Doppelwänden wird die erste Schale des Elementes, die bereits ausgehärtet ist, auf der Station 1 mit dem Entschalgerät auf einen Vakuum-Rost daneben plaziert. 

Bild 14 "Vakuumrost"


Danach fährt der Rost in die Wendestation 10, wird von der Hubeinrichtung angehoben und dreht seinen Rahmen mit den darauf angesaugten Platten in der Längsachse um 180°.

Bild 15 "Wendevorgang"

Das Regalfahrzeug holt aus der Betonierstation eine Palette mit Frischbeton und transportiert diese zur Wendestation.

Die Palette auf Station 8 ist mit den äquivalenten zweiten Schalen zu den Platten auf dem Rost geschaltet und betoniert.

Der Vakuum-Wenderost senkt nun die erste Schale auf die zweite Schale mit einer einstellbaren Distanz ab.

Bild 16 "Verbinden zweier Wandschalen"

Ist diese Distanz Null, entsteht eine Vollmassivwand mit 2 hochwertigen Oberflächen. Das Verbinden der beiden Elemente geschieht durch Einrütteln der Gitterträger der ersten Schale in die zweite Schale.

Bild 17 (Folie) "Längsschnitt Mischanlage"

Die Mischanlage ist in die gesamte Werksstruktur materialflußgerecht integriert. Sie zeichnet sich dadurch aus, daß die komplette Technik innerhalb eines abgeschlossenen Gebäudes untergebracht ist und somit keinerlei Emmissionen nach außen dringen. Dies ist deshalb besonders wichtig, da es
wirtschaftlich notwendig ist, die hochwertige Technologie intensiv im Mehrschichtbetrieb zu nutzen und somit insbesondere Lärm nach außen zu vermeiden. In der Zuschlagstoffbeschickung werden die Betriebskosten durch einen 35 to - Brückenkran-Aufzug besonders günstig beeinflußt. Im Mischen-Konzept ist die als Schallschutzkammer ausgebildete Rüttelstation, die Betonübergabe an eine Kübelbahn, an einen weiteren Betonverteiler bzw. an Transportmischer enthalten. Die Zusammenfassung der Betonübernahmestellen ermöglicht ein direkt darunter angeordnetes Recyclingsystem.

Bild 18 "Betonverteiler über Recyclinganlage"

Dies war nur ein Beispiel. Die gleichen Überlegungen gelten für Aufgaben im Industriebau wie im Wohnungsbau.

Wie können wir uns nun, ausgehend von dieser Basis, die Zukunft vorstellen?


Unsere Vision ist, die Fertigungstechnologie in bezug auf Lohn- und Materialkosten, in bezug auf Qualität und Flexibilität so weit zu entwickeln, daß sich die Bauarbeiten vor Ort auf reine Montagearbeiten beschränken.

Fertigteilfabrik PMS 2000

Mit dem gezeigten Entwurf einer Fertigteilfabrik lassen sich sämtliche Teile der vorgenannten Aufgabenstellung derart herstellen, daß die Produktionseinheiten komplette Wohnungen sind. Die hochwertigen Oberflächen lassen ein Streichen oder Tapezieren von Wand und Decke ohne Verputz zu. Außen sind die Fassaden ebenfalls fertig.
Die Sanitärzellen aus dem Fertigteilkwerk brauchen vor Ort lediglich an Strom, Wasser und Abwasser angeschlossen zu werden. Ansonsten erfolgt der Ausbau im Werk.

Treppenläufe, Aufzugsschächte und sonstige Kleinteile ergänzen ein komplettes System der Zukunft.

Innerhalb des Werkes reduzieren sich die Lohnkosten weiter, indem beim Betonieren eine flexible und sensible Steuerung auf die Betonkonsistenz eingeht und die Nacharbeiten wie Scheiben und Glätten durch CAD-Daten exakt gesteuert von Robotern ausgeführt werden.

Beim Einschalen werden zusammen mit Systemschalungen Roboter gute Dienste leisten. Die Schalungen, auf die der Roboter zurückgreift, verwaltet der Leitrechner in bekannter Lagertechnik.

Ich denke, daß wir diesbezüglich erste Ansätze ab 1993 zeigen können.

Die Stahlverarbeitung ist bei der Elementdecken- und Wandproduktion, wie schon gezeigt, bereits sehr weit automatisiert.

Im Industriebau sind hier noch große Aufgaben zu lösen. Die Weiterentwicklung der Schweißtechnik wird uns vom Baustahlgewebe unabhängig machen und dies bei größerer Flexibilität bezüglich der Bewehrungsquerschnitte.

Konsequent durchgeplante Arbeitsplatzeinrichtungen reduzieren auf konventionellem Wege die Lohnkosten und sind die Vorstufe zur Mechanisierung der Flechtvorgänge.
Im Bewehrungsbereich der Zukunft ist die Verarbeitung des Rundstahles vom Ring sowohl für gerade Stäbe als auch in Bügelformen nicht mehr wegzudenken. Kurzfristig wird eine rechnergestützte Lagerflächenverwaltung für mehr Ordnung und Übersichtlichkeit sorgen. Stand der Technik ist es schon heute, montagefreundlich kommissionierte Montageeinheiten direkt zusammenzustellen.

Bild 20 "Doppelwände Transportgestell" als Logistikeinheit

Somit sinken die Standzeiten der Lkw's bei der Beladung erheblich. Mit den Daten der Lagerflächenverwaltung läßt sich als weiterer Schritt der Lagerportalkran automatisieren.

Überleben wird das Betonwerk, welches Innovation gezielt und planmäßig betreibt und Weiterentwicklung nicht dem Zufall überläßt.

Stellen sie sich deshalb bei ihren Zukunftüberlegungen folgende Fragen:

Entspricht ihr Produktionsprogramm den Wünschen ihrer Kunden und wie sollte es gegebenenfalls ergänzt werden.

Wie hoch ist der gesamte Lohnaufwand in ihrer Produktion?

Ist für ihr Investitionsvorhaben eine zukunftssichere Studie erstellt worden, die untersucht wie und ob überhaupt Zukunftsmöglichkeiten gegeben sind. Sie untersucht sowohl die zukünftige Personalsituation in Büro und Betrieb als auch die technische und logistische Planung ihrer.
neuen Produktionsstätte von Anlieferung der Rohstoffe bis zum Ausliefern der fertigen Produkte.

Nur wenn Sie alle diese Fragen mit "Ja" beantworten können, haben Sie die richtige Weichenstellung zur Sicherung Ihres Unternehmens getroffen.

(Im letzten Teil des Vortrages wird an einigen Beispielen der Erfolg unserer Kunden, die sie mit dem Betrieb ihrer automatischen Betonwerke haben, beschrieben und auf richtungweisende Trends eingegangen.)
SESSION 3

LOGISTICS/TRANSPORT ASSEMBLY
Quality and logistics in the building industry from the perspective of the supplier

F.M.G. Smulders
Quality and longevity in the building industry
from the perspective of the supplier

M. S. Bombardier
I. Introduction

One Sunday morning I sat in the garden and pondered over the topic of this lecture. I was continually distracted by the whistling of a visitor who passed by with some regularity. He was clearly determined that my presence should not affect his activities. Tireless, he shuttled back and forth, on the way busily collecting the diverse materials for a task that requires a thorough knowledge of building techniques: making a nest. While the blackbird in question had presumably never followed a course in logistics, he was a past master in materials flow and in particular the control of materials flow. Consequently, the nest was habitable at the very moment mother blackbird needed it - Just in Time!

The building process can be characterized by short or long materials flow paths. In the first case, raw materials are used directly, without intermediate steps, to produce the construction. In the second, the raw materials are processed in stages and the final construction is the end result of a chain of intermediate part products.

An example of a long materials flow path is that involved in building a utility, such as an office block. This is particularly so if the office block is constructed using prefabricated concrete elements.

I have already used a number of terms which are important in logistics, in particular materials flow and process. My view of logistics is that its central tenet is and always will be: THE CONTROL OF MATERIALS FLOW
The term control implies a process with input-output-goals-management-and means. The goals of the logistic process concern such matters as:

* delivery time
* cost
* quality
* flexibility

As the title indicates, my topic is control of the logistic process as a means to realizing the desired quality in the object to be built. However, it is not possible from this point on merely to ignore two other goals mentioned above, namely cost and delivery time. They are recurring themes, for what is quality without cost control? Likewise, implementing the right delivery time has everything to do with quality, not to mention flexibility.
II. Materials flow

Consider the construction process of the office block in prefabricated concrete mentioned above. What are the relevant material flows and what conditions must they satisfy?

To begin with the latter: the materials flow must be controlled in such a way as to ensure the right materials in the right quantity at the right place and the right time.

In this case, the right materials are simple, namely:

Raw materials are processed in the factory to form prefabricated concrete elements. And these prefabricated elements are assembled on site to form the skeleton or facade of our office block. The flows are outlined in Figure 3. Here, following the logistic conventions, are to be found squares, which denote activities and triangles which represent storage of goods, intermediate products.

Reality is not so simple as the representation of Figure 3.
Firstly, the prefabricated concrete elements must be transported from the factory to the building site. For the supplier, this transport is not merely a necessity but can serve as an indication of quality. To illustrate this we take a brief excursion from our prefabricated office block to visit a supplier of prefabricated concrete floors for houses. In the figure a simple building plan is illustrated. This comprises 4 apartments, two at the ends and two in between.
Every apartment comprises 6 prefabricated concrete slabs and due to the form and reinforcement required, there are 12 different sorts of slabs. The contractor has at his disposal a mobile crane and mounts the slabs from left to right and back to front. Furthermore, the slabs are transferred from the transport vehicle directly into the building. Consequently, the prefab supplier delivers (amongst other things) pure quality if the vehicle is loaded in such a way that the topmost slab of the pile is just that which must be positioned 'back left', while the next one under comes 'back left minus one' etc. Clearly, this simple looking aspect of quality has implications for the production process, the planning process and even for the engineering process (consider the reinforcing). This is a purely logistic problem, which has far reaching implications for such critical matters (mentioned above) as delivery time, cost control and quality.
We now return to the materials flow of our prefabricated office block. From the discussion up to this point it looks as if all the raw materials come together at a single point and are there incorporated into prefabricated concrete elements. This is however not the case. Because of this and the process control discussed later, the raw materials must be divided up into:

- Raw materials incorporated in the element for its constructive function in the building.
- Parts which are incorporated in the element for the services in the building.
- Parts which are incorporated in the element to ensure the integrity of the building.
- Parts which serve for the assembly of the skeleton.

All of these raw materials and parts undergo different fabrication processes and these processes, or more correctly part processes, have so-called nodal points.
Recognizing these nodal points correctly is important for giving the flow of necessary information in the most general sense and is thus of critical importance for control of the logistic process and thus achieving the goals: delivery time, cost, quality and flexibility.

III. Building market

In the above, the materials flow has been examined. The term control has frequently been used but, what is meant by it; what or - if you prefer - whom does one control?

We have already considered the consequences if the materials flow is not controlled in the building industry, namely intermediate storage with the extra transportation this entails. These extra operations require extra organization and extra information flow and thus entail unnecessary costs and the chance of quality degradation.

To control materials flow and thus specify costs, delivery time and quality, there is only a single point of departure, the building market.

The building market is the reason for our existence, without a single exception.

We builders, or better we building partners are obliged to serve the client in an optimal way.

As building partners, we deliver one single product, namely a building, viaduct, sewer or whatever. To do so, we need to know the wishes of our client. Only if the wishes of the client are known well enough to avoid any misunderstanding, can we serve him optimally. This is done partly by means of smooth functioning primary processes with all the necessary control measures and partly by providing a service as integrated as required. Remember the concept primary processes as well as control and integration. At this point I return to the wishes of the client, or, if you will, the principal.
Analyzing a client’s wishes is not an easy task in all events, but this is particularly so in the building industry. It is singularly difficult to understand the wishes of the client when he is unable to express them either because he does not recognize the problems or is not aware of the possibilities available and their limitations.

I am not, of course, saying that every building partner should not continually analyze his market or market segment. On the contrary, this must definitely be done and here strategic analyses using product-market matrices, competitor profiles, etc. have repeatedly proven their value. But the architect remains the person in each specific case, for every new building, who must translate the explicit and implicit wishes of the principal into the requirements to which the building work must conform.
To this point everything follows logically, or rather logistically and in this way the building industry today serves the client in an optimal way. Somehow I feel some doubt on your part about this statement. And this has everything to do with the mentioned primary processes, control and integration.

IV. Primary processes

The building process as a whole can be divided into the phases of initiation, design and execution.

In the initiation phase, it is primarily the principal, who undertakes action.

In the design phase, the architect translates the wishes of the client. Later, definitive plans are drawn up in consultation between architect, chief builder and installation adviser.
In the execution phase, the contractor, suppliers of prefab. elements and installations make the relevant preparations and carry out whatever is required of them, so that the building can be handed over to the client.
V. Design phase

As already noted, in this phase, the architect and his advisers are responsible for translating the wishes of the principal. This translation goes through a number of stages, but the design phase is always followed, after a series of preliminary stages, by a definitive plan.

This definitive plan is the crystallization in drawings and specifications of the requirements of the builder. It is a product of the knowledge, experience and flair of the architect, chief builder and possibly other advisers.

Every contractor and every supplier has his particular strong points in knowledge, organization, product technology etc. Consequently, it seems to me that it would be advisable if the contractor and suppliers were to be involved in the preparation of the definitive plan.
To round off the design phase, with an eye on the logistic manager, I pleaed for the formation of a construction team in the phase of definitive drawing. In my view, a construction team is the trigger that is needed to come to an appropriate definitive plan. This is the basis for the controlled integration of the necessary processes, that lead to the product the client desires. Only then it is possible that the client’s requirements can be transformed into internal standards of achievement for the activities of the disparate building partners. Without these internal standards no industry at all can so control its processes that quality, in the sense of optimal customer service, is guaranteed.

VI. Implementation phase

![Diagram](attachment:building_process_diagram.png)

Above, I have argued the case for integration of knowledge in the last part of the design phase, with as output 100% certainty about the internal standards in the building
industry. Moreover, in my view, there are a number of things which can be improved in the current practice of execution itself. Every party involved in implementation can divide his process into a preparatory part and implementation part. We may assume that, using internal standards, the preparation for production and the production of the firm's own product do not give rise to any problems. The modern prefab. industry has in particular had experience for some time with quality norms following the NEN-ISO-9000 series.

In this way, the choice has been made in principle for quality assurance in place of quality testing. It seems to us that the classical approach is quality testing at the end of the production process. In this case, the emphasis lies upon the isolated responsibility of the quality officer.

![Diagram of Quality Control and Assurance](image)

In terms of quality assurance methodology, this approach is totally inadequate. Quality testing at the end does not sufficiently guarantee delivery time. Every product which does not satisfy the norm is rejected and this implies waste of both material and energy. Furthermore, extra costs are
involved in repair and in control of the extra tasks, which must be carried out with speed, outside of any pre-arranged plan. Quality control, on the other hand involves complete control of quality during the production process itself, together with security about the quality of the input. The accent lies upon the personal responsibility of everyone involved in the process and the point of departure is: first time right. Our blackbird would approve!

**Total preparation** remains absolutely necessary and not only must it approach perfection in the sense of technical responsibility. But it must, in addition involve good planning and complete conformity to the plans. To put it another way, preparation which is technically competent, which holds to internal planning and makes allowance for transport and assembly, but which does not involve the processes of the other building partners cannot lead to problem-free execution. This leads to the necessity for integration, which must be done in a controlled manner. In other words, the internal standards of the building associates must be adjusted to each other, so that the outputs of the different partners lead optimally to one single product. This implies that this integration process requires its own management, with its own ways and means, such as a unified planning for exchange of relevant information between the diverse building associates.

In order to control the integration process the necessary information flow must be planned according to a given scheme and must conform to previously formulated quality norms.
REQUIREMENTS OF PRINCIPAL

OPERATIONAL CONTROL

PLANS OF ARCHITECT CHIEF ENGINEER

Figure 12
CONCLUSION

A building should be an optimal product, which embodies the requirements of the builder. It is a product that comes into being by the cooperation of different building partners. This cooperative process only leads to an optimal product if the requirements from the design phase give rise to quality standards which are geared to the disparate part processes, via a process of integration.

As noted above, my view is that the diverse building partners should be involved in the phase of definitive planning. In addition, it must be recognized that integration in the execution phase is possible only via a controlled process, a process with its own input, output, management and resources. Only then is it possible to control information flow and thus materials flow, to produce an optimal total product.

The prefabricated concrete industry has in the past played a leading role in the integration process by the use of quality guarantee systems, as well as expertise in the areas of development, project management and knowledge of the production methods of the disparate building associates.

Finally, I must share the joyful news that our blackbird has laid its first egg - just in time! Thank you for your attention.

Ir. F.M.G. Smulders
Some aspects of logistic planning

C. Quartel
1. INTRODUCTION

"To built is to transport"

This statement expresses clearly the building process of today.

Looking back over the last thirty years you will see the change from a simple traditional building activity, with an assemblage of an enormous amount of small separate basic materials, into an application of voluminous and heavy parts erected and assembled fast and easy by means of modern and high capacity equipment.

An example of this development is shown in fig. 1.

This figure shows the growth of length and weight of factory-precast bridgebeams during the last 40 years.

Starting with beams of 15 m. length and 5 ton’s weight now we passed the 50 m. length and 115 ton’s weight.

It will be clear that the development of new and heavy mobile cranes has also stimulated this growth.

And this development will go on.

![Graph](attachment:graph.png)

Fig.1: Growth of length and weight of precast bridgebeams in the Netherlands during the last 40 years

1.1. Logistics becomes more and more important

The target for the future is to reduce as much labour on site as possible.

This will require well equipped factories to provide all necessary building parts, produced under good, safe and also pleasant conditions.

This will require well designed standardised connections.

This will also require good transportation and assembly methods.
And last but not least this will also require a sophisticated system to control all the steps of the whole process in order to increase the efficiency to the highest level. "Just in time" and "small supplies" are the general keywords.

A recent example comes from Japan where the well known firm of Obayashi developed a 100 % automated building site. A factory on site with an output of one new building structure.

This Super Construction Factory (SCF) contains an automatic stockyard and an automatic transportation system.

All steps of the building process are controlled by a computer. So only some operators are required to build a multistory office building by means of all kinds of robots (Figure 2). [1]

The big advantage is that these robots can work during twenty four hours a day just with the assemblage of prepared components.

Connections between the parts are simplified to "one touch fasteners".

Fig.2: The fully automated building system developed by the Obayashi company
2. THE LOGISTIC PLAN

The application of factory-precast elements can be separated roughly into two different processes: production and assemblage.

The first process deals with the flow of rough materials like cement, aggregates, reinforcement, prestressing materials and other parts.

In general the "assemblage" of these materials will take place in moulds.

The second process deals with all the physical movements of the ready elements from the production spot to the final position where it will be a part of the building structure.

A logistic plan describes all the necessary activities to get the elements on the final spot in an efficient and economic way.

Fig. 3 shows the separate stages of the second process as described in the logistic plan.
2.1. Logistics as part of the design

In general the logistic plan should be the result of a logistic study in which the whole building process has been optimized in order to reduce the total costs as much as possible.

This study should be carried out already during the design stage in close cooperation with the contractor(s) and the precast company.

Computersimulation and an logistic parameter study must support this activity.

There are two conflicting aspects to consider:

1. From a point of view of "building site-economy" a constant assembly speed requires also a constant supply of elements to be erected directly from the truck and just in time.

2. From a point of view of "production-economy" a constant production of similar elements is required.

The use of moulds and the changes of moulds are well planned and the number of workers involved is stabilized over a long period and well-fitting in the overall factory planning.

This will result in a minimum on production costs.

The conflict between those two aspects results in the need for a stock. This stock is often situated near the precast factory where cranes and lorries are available.

Because all goods and elements stocked on the factory site represent capital the target must be to reduce the number of stocked elements as much as possible.

Besides this also other reasons can require a reduction of stocked elements like crane capacity and stock capacity.

2.2. The logistic study

The parameters of the logistic study are:

- a. the total timeschedule of the building activities
- b. the building sequence of different building parts
- c. the break down of the structure into separate (prefabricated) parts
- d. the production capacity of the precast factory.
e. the use of moulds
f. the variety of element types
g. the capacity of stockyards
h. transportation methods
i. complexity of the connections to be made on site.

The investigation must result in a total schedule of the flow of elements in position and time.
From elements with one or more extraordinary dimensions also the orientation has to be defined.

2.3. Logistic planning: still at the beginning
Today's reality shows that other conditions still dominate the completion of a logistic plan:
the timeschedule has been set already before any contractor or precast company is involved.
When not enough time is left for a good preparation the only concern will be how to finish the production just in time in spite of how to minimalise the costs of production.

3. Precast beams for Van Brienenoordbridge: an example of logistic planning

3.1. Introduction
The Van Brienenoordbridge, one of the main north-south motorways (A16) in the Netherlands, passes the river Maas near Rotterdam.
The bridge was built in 1964.
Twenty years later an increased traffic volume lead to long traffic queues everyday.
In 1984 it was decided to double the existing bridge with a new bridge.
As far as dimensions are concerned, it is more or less a copy of the first bridge:
a main span of almost 300 meters, formed by a steel arch and on each side an approach bridge with 9 spans of 50 meters.
When the first bridge was built in 1964, the 50 m. long concrete beams were made on site. For the second bridge a choice has been made to make the beams elsewhere in a factory.
They are the longest prefab beams ever made in a Dutch factory.
The length of the beams varies from 50.65 m. to 52.80 m. with a maximum weight of 114 tonnes. The beams are 2.60 m. deep and I-shaped with a bottom flange of 1180 mm. width and a top flange width of 500 mm.

The beams are prestressed with prestretched steel. To achieve the necessary prestressing force 100 strands (12.5 mm Fep1860) were required.

Every approach span consists of 9 beams, the total width of the bridge is 27 m.

After the erection of the beams reinforced concrete slabs (70 mm thickness) were placed on the beams. A cast on site topping of 150 mm. composed all parts to one bridgedeck structure.

Totally 162 beams VIP 2600/1180 were ordered by Rijkswaterstaat, the Dutch bridge authority.

The beams were produced by Schokbeton in the factory in koudekerk aan den Rijn.

Schokbeton was also responsible for the design, transportation and erection of the beams.

The site activities started in july 1987 and the bridge was ready in may 1990.

3.2 The Logistic plan

There were several reasons for a detailed logistic investigation:

a. The dimensions and the extreme weight reduced the possibilities to move and rotate the beams.

b. Transportation and erection required the application of special and expensive equipment like heavy mobile cranes and pontoons. A detailed plan was needed to control the costs of this equipment.

c. The contractor proposed Rijkswaterstaat to shorten the initial timeschedule with almost 1.5 year.

Schokbeton was also able to tune the production plan on this fast timeschedule which resulted in a total duration of production of only 18 months.

This fast schedule however did not allow any disturb and required a well detailed planningsystem.

The study started with an investigation of all the restrictions and conditions of the different stages during production and erection:
- position of the mould in the factory
- demoulding and transportation to the stockyard
- stockpositions and stockcapacity (cranes)
- transportation on the factory site to the pontoons
- loading of the pontoons
- route of the pontoons to the building site
- positions of cranes on the building site
- deloading of pontoons near the building site
- erection of the beams to the final position

All the movements and positions are schematically shown in fig. 4.

The logistic plan was influenced by some interesting items:

- The stockcapacity on the factory site is determined by the available cranes and their radius of action. The capacity could be increased by a second row of 11 beams at the top of the first row of 12 beams.
  So the sequence of deloading of the beams from stock is more or less the opposite of the sequence of stocking of the beams.

- The loading and deloading of a pontoon results in all kinds of different sideways rotations of the ponton.
  This will also influence the behaviour of the beams. To ensure the stability of the beams a controlled rotation could be obtained by a certain loading sequence in combination with waterballast in some holds of the pontoon.
  The volume of ballastwater differed per loadingstep, which could be arranged by means of a pump.
  Besides this the pontoons had to turn during deloading near the building site to bring beams in the radius of action.
  The result of this was that the deloadingsequence differed from the loading-sequence.

The study resulted in:

- an erectionplan: a detailed description of the sequence of beams to erect according the overall timeschedule

- a productionplan which is based on the schedule and sequence of erection of the beams on the building site.
  Also the orientation of the beams had to be determined with respekt to all the movements and rotations during the total transportation
TRANSPORT PER LORRY

OPSLAG IN 2 LAGEN OP 3 VELDEN
DWARSTRANSPORT MET PORTAALKRANEN

TRANSPORT MET PLATFORMWAGENS

OP DEFINITIEVE PLAATS BRENGEN MET MOBIELE KRANEN

Fig. 4: scheme of the routing of the beams from the factoryhall towards the final position on the building site.
- a stockplan which exactly described the positions of the beams on the stock including an "input and output"-schedule

- a transportationplan which described the positions on the pontoon, the loading and deloading sequence and the orientation of the beams. A ballastplan described the ballast volumes to be pumped in and out and the expected rotations of the pontoon.

3.3 Conclusion

On the one hand the logistic study was simple and clear because only one type of element was applied.

On the other hand the plan was an absolute requirement because all the stages were strongly related to each other.

For instance one wrong orientated beam on the pontoon could disturb the whole process and effect the costs directly due to all the expensive equipment.

The preparation of the logistic plan took up a lot of time at the start of the projekt from all the participants but the advantage was that the whole process could be managed clearly and easily: Modifications were easy to arrange and everyone knew what to do.

The conclusion may be that a good logistic study at the start of a project may require some extra expenses but it will save a lot of money during the whole project.

4. REFERENCES

1. POLY TECHNISCH WEEKBLAD 1992 NR 33/34.
   Japans bouwbedrijf ontwikkelt volautomatische bouwplaats
Building traffic management in congested urban areas

W. Steiger
TRAFFIC MANAGEMENT IN CONGESTED URBAN AREAS

1. INTRODUCTION
Traffic requirements for the supply and waste disposal for construction sites are particularly dramatic in congested urban areas. 35% to 50% of the road freight traffic is construction traffic. Large commercial vehicles move from one construction site to the next at "stop-go speeds" in peak periods. At the same time, it is noticeable that such means of transport as ships and railways, which are particularly suited for bulky goods are not sufficiently used though being optimally positioned in town centers. Dissatisfaction by all participants in the system is increasing as can be seen from the example of a study on congestion in Berlin. This situation presents challenge for an effective management of the construction traffic, with the objective of achieving an effective traffic relief by coordinated planning and control of the supply and waste disposal for construction sites.

2. PROCEDURE

2.1 Important limiting conditions
It has been clear from the start that the efficiency of the traffic management for construction sites depends decisively on the cooperation and acceptance by all participants, i.e. the population and the construction and transport industries. Only that way can feasible suggestions for solutions be developed and enforced. Figure 1 explains the situation with regard to the interests of these system participants. In the planned coordination of activities relating to constructional logistics it has to be ensured, in any case, that the individual measures are as compatible with the market as possible, i.e. without intervening in the construction industry market sector.

2.2 Determination of construction traffic volumes
Initially it was necessary to elaborate the fundamentals for determining the construction traffic volumes of the most different types of site, see fig. 2. The resulting quantities per 10,000 m$^3$ of enclosed area show the high percentage (more than 95%) of bulky goods in the form of excavated soil and aggregates. The traffic volumes calculated on the basis of these fundamental data for the center of the congested area alone (fig. 3) show that traffic minimization on the roads is an indispensable prerequisite for a generally acceptable supply and waste disposal for construction sites.

2.3 Possibilities of traffic avoidance
A closer look at the results of analysis of bulk building materials shows that building waste (excavated material and rubbish) makes up approximately fifty percent of the
materials to be transported. In many cases, this building waste is still disposed of with great effort and with high costs for transport and dumps, even though recycling possibilities have markedly improved in recent years and, by virtue of mobile technologies, can often be performed actually on the construction site. Careful consideration must be given to the question what proportion of the excavated material can remain at the construction site in the form of aggregates or as backfill. With major construction sites it is usually better and more efficient to produce the in-situ concrete with large concrete-mixing facilities at the construction site itself, i.e. there is no need for the delivery or removal of aggregates, which is recycled at the construction site. Naturally, the rate of re-use of the recycled excavated material is dependent upon the soil quality at the individual site. As a rule, soil quality is determined through soil analyses preceding the actual excavation. On a major construction site in downtown Cologne, for instance, the excavated material was consequently used as aggregates and as modelling material for the parks so that there was no need for the disposal of excavated material and, equally no need for the delivery of sand and gravel.

2.4 Possibilities of traffic reduction
When all the possibilities of traffic avoidance have been exhausted, it is important to shorten the distances to the construction sites by moving external logistic capacities as close as possible to the site and by increasing the capacities of adjacent stock, transshipment and production locations in order to cut back on truck traffic. Possibilities for this often exist in the center of urban areas, at freight stations and port facilities. These sites offer the significant benefit that they can be accessed quite easily outside the service hours of a construction site, i.e. at nighttime. These possibilities for the reduction of traffic pose a major challenge for construction traffic management since they demand high overall flexibility in order to make optimum use of the available resources in cooperation with all system partners involved. This requires detailed consideration and arrangement of the technical and organizational procedures in advance of the actual construction. The arrangement includes the transport chain for bulk goods as well as the transport of general cargo, which is defined rather by its volume and variety than its weight. On account of the frequently urgent need to procure small batches, these general cargo transports cause considerable traffic congestion. It is therefore important - unless buffer stocks are available on the construction site - to make allowance in the planning phase and together with the planning authorities, for space for so-called "construction shops" in the vicinity of the construction sites. Only in this way is it possible to achieve the intended aim of concentrating traffic, thus reducing it significantly whilst at the same time improving service quality. A further possibility of reducing construction traffic is the creation of an "exchange" for building waste, which gathers and distributes information on the supply and demand of building waste, including information on quality, target date, location, price and logistical requirements (transshipment and transport).
The effect of this public exchange is twofold. The building waste dumps, which are a problem in any case, become smaller, and traffic is relieved by reducing transshipment and transport processes.

For this building waste exchange to be successful, the production of and demand for building waste has to be reported to the exchange as early as possible. As a rule, this is possible as soon as the building project is licensed by the approving authority. This means that, in addition to the classic construction criteria, logistical criteria have to be included in the approval procedure, in order, as early as the construction planning phase, to set the course for an optimum traffic management. The related procedure is depicted in fig. 4.

2.5 Greater use of rail and water transport

To look at the already integrated water and rail transport systems is to recognise that here, ready and waiting, is a particularly suitable means of transport for bulk goods, and that these goods can be transported much more efficiently via the rail and water networks.

If, however, in spite of this, road transport is used for the majority of the bulk and heavy goods traffic, the main reason is that too little consideration generally is given to an integrated solution to the logistics problem in the construction industry. This means that existing links between the various means of transport are not organized in a sufficiently rational and economical manner. The preparations necessary for the transshipment of goods would frequently lead to enormous costs and thus to a decision against the use of both rail and water transport.

The construction industry requires the most complete logistical service at the most favorable price, totally regardless of which form of transport is used. The right partner for this logistical service for construction must therefore bring a high level of understanding of the problems and put the quality of service to the test through the specific introduction of water and rail transport.

The following ideas were developed as a solution for use in the center of Berlin:

- Introduction of the use of the railway in the southern part of the city via the goods stations which are directly adjacent to the building sites. For aggregates and nonusable excavated material, containers which are suitable for both road and rail can be employed.
  The measures required for recycling and the mixing of concrete on site can also take place at the goods stations.
  The space required for the so-called "construction shops" can also be reserved close to the construction site.

- In particular, introduction of water transport for the northern sector via the waterways and use of the harbor facilities for intermediate storage, recycling and preparation of concrete.
2.6 Setting-up of control centers for constructional logistics (BAULOG-Leitstand)

On the basis of the planning concept developed above and technical and organizational preparation, all of the control and supervision of the relevant construction site traffic will be taken over with the help of a control center for constructional logistics. This working base for construction traffic management collects all the necessary data for the appropriate supply and disposal measures for the construction program and makes it available to those involved in a processed form which fits their particular aims. A computer-assisted information system will be developed, but, for the present, the normal channels of data communication can be used (Fax etc).

3. Summary

Traffic management in congested urban areas has to be performed dynamically and on a broad basis to enable a system of integrated constructional logistics. An efficient working base to this end are control centers for constructional logistics (BAULOG-LEI'TSTAND) which are responsible for the planning, control and supervision of constructional logistics measures on major construction sites in coordination with all the system partners. Only in this way can the objective of a generally accepted, efficient supply and waste disposal for construction sites in heavily congested urban areas be attained.
Objectives: "Constructional logistics in congested urban areas"

What should be achieved by "constructional logistics"?

City development
- Population
- Reduction of construction site traffic
- Road traffic relief
- Reduction of environmental loads
- City-compatible supply and waste disposal for construction sites
- Increased acceptance of goods traffic
- Contribution to the concept of "logistic modules for urban areas"

Construction industry
- Supply with construction material "just in time"
- Controlled construction waste disposal
- Construction rubbish recycling
- Cost-effective supply and waste disposal
- Supply and waste disposal by one company (proposal)
- Separation of logistic functions

Transport industry
- Better use to capacity
- Reduction of waiting times
- Increased use of railways and inland waterway craft
- Reduction of transport and transshipment cost
- New proposal "Integrated supply and waste disposal for construction sites"
- New logistic services
- Wide-area linking
Type of construction site A 2.1
Basic data for 10,000 m³ of enclosed area in tons

**Soil excavation**
- Sand: 3156 tons
- Marl: 1264 tons
- Gravel + Sand (rubbish): 1056 tons
- Filler material: 629 tons
- Rubble: 517 tons

**Waste**
- Masonry: 133.7 tons (24.1%)
- Floor finish: 15.5 tons (2.3%)
- Mortar (plaster): 30.1 tons (0.5%)
- Glass: 19.5 tons (0.4%)
- Insulation: 14.2 tons (0.3%)
- Dry construction: 12.4 tons (0.2%)
- Chemicals: 10.4 tons (0.2%)
- Plastics: 9.7 tons (0.2%)
- Other organic materials: 6.8 tons (0.1%)
- Wood: 2.5 tons (0.1%)
- Tiles: 2.4 tons (<0.1%)

**Other organic materials**
- 6.6 tons (0.1%)

**Construction material**
- Concrete: 4545 tons (82.5%)
- Gravel: 406 tons (7.4%)
- Sand: 262 tons (4.8%)

**Supporting facilities**
- 73 tons (0.1%)

**Construction site installations**
- 73 tons (0.1%)

**Scaffolding**
- 22.5 tons (0.1%)

**Concrete forms**
- 2.3 tons (0.01%)
Characteristic figures

Traffic cells 111 Leipziger Platz and 114 Otto-Grotewohl-Str.

Annual long-haul road freight traffic volume 28,322 to 546,988 t annually

- incl. railway route to Leipziger Platz (900 m)
- no continuation of railway line, no station
- without vehicular tunnel

* Peak value
PLANNING AND CONTROL

Building sponsor
Design  Planning

Construction approval (Senate)
Building  Traffic/Transport  Environment

Service companies
Building contractors  Carriers  Waste disposal companies

Construction site
Control

Prerequisite: coordination of processes
Production and erection of large elements of Storebælt West bridge

J.P. Serlé
1. INTRODUCTION
The fixed link across the Great Belt forms an important part of the main rail and road systems in Denmark. The total length will be approximately 18 km. and will connect Zealand with Fuenen. The Great Belt is divided by a small island Sprogø into a West and an East channel.

Presently, E.S.G. [1] is constructing the West Bridge, the 6 km. long rail- and road bridge between Knudshoved and Sprogø. The alternative design developed by E.S.G. is based on the prefabrication of large concrete units. These units, for substructure as well as for superstructure, are brought in place using only one specially designed lifting vessel called Swan (Svanen).
2. DESIGN

2.1 Alignment
The alignment of the West Bridge shows a horizontal curvature of 20,000 m, mainly for architectural reasons. A navigation channel with a clearance of 18 m is obtained by a vertical curvature of 500,000 m. The main navigation channel of the Great Belt however is situated in the East Channel.

2.2. Superstructure
The cross section of the alternative design shows one box girder for the railway and one for the roadway. The arched girders cantilever approximately 54 m to either side of the central bearing. The height of the girders varies from 8.60 m to 5.10 m for the railway and from 7.25 to 3.75 m for the roadway. After erection 10 or 11 units are longitudinally joined together to form a continuous beam. Post tensioning is applied by the VSL-system using longitudinal cables of 22 strands and across cables of 4 strands.
2.3 Substructure
Each girder is supported by a separate piershaft, matching the bottom width of
the girders and measuring 5 m in the other direction. Both piershafts of one
span are placed on top of one caisson, which is resting on a compacted and
levelled stone bed. Each caisson consists of a bottomslab of 1.20 m thick,
gridwalls forming 3 x 6 cells and a shaft on top of the middle row of cells. The
bottom grid measures 17 x 29 m, varying in height from 5 to 10 m.
The piershafts come in lengths from 8 m to 24 m. They are connected via a cast
in-situ joint to the caisson top slab.

3. PREFABRICATION PRINCIPLE
The tenderpapers already called for large prefabricated or assembled units to be
erected in a variety of methods. Carrying these ideas further, E.S.G. opted for a
design which allows all units to be erected using only one lifting device. In this
way the obvious advantages of prefabrication, controlled production and reduced
offshore work, are combined with optimal use of equipment and minimal
amount of concrete in situ. Concrete elements are prefabricated weighing from
1000 tons for a single piershaft, 4200 ton and 5700 ton for rail- and respectively
roadgirder to 6200 tons for the largest caisson.

4. PRODUCTION
4.1 Principle
In general, prefabricated units are handled by cranes for horizontal and vertical
transport from casting position to storage and further to truck or barge. Based
on the principle of handling off-shore modules and incremental launching of
bridges, a system was developed, which requires no lifting but only horizontal
skidding. Making use of the low friction between stainless steal and PTFE, less
than 5%, not more than 300 tons horizontal force is needed to move 6000 tons.
300 ton can easily be supplied by 2 hydraulic jack of 150 ton each.
Each type of unit is subdivided into a number of consecutive steps. This division
is not only dictated by the geometrical form, but also by the principle of a
constant daily production of reinforcing steel, posttensioning and concrete.
The units are produced on a production line, where they are pushed from one
casting position into the next one and thus growing along the line into their final
state. Each station along the line has its own set of formwork and production
equipment. In this way a number of units is under construction at the same time
and this flow production is capable of turning out one complete span per 6 day
cycle.
The prefabrication yard measures approximately 300 x 800 m, with the waterfront facing south. The concrete and reinforcing steel area is located centrally between piershaft and railgirder to the West and caisson and roadgirder to the East.

4.2 **Caissons**

The caissons are subdivided into the following parts:
1. Bottom slab
2. Grid walls and caisson shaft
3. Plinth

Caissons are produced on two adjacent production lines in a twelve day cycle. Following production stations can be distinguished:
1. Bottom - on the movable mid section of the steel bottom mould the reinforcing steel cage of the bottom slab is assembled and moves into position;
2. Here the bottom slab is poured and caisson walls slipformed. The complete slipform is suspended from a large gantry with moves between the two production lines. As soon as the gantry is moved, the caisson is pushed into position.
3. Here the plinth is poured, using precast concrete planks as formwork for the underside.
4.3 Piershafts.
The piershafts are subdivided into the following parts:
1. Undersection of maximal 12 m high
2. Intermediate section of maximal 6 m high
3. Piershaft head.
Both piershafts for one caisson are made simultaneously in vertical position on a steel base frame. Frame plus shafts are pushed from station to station. Between the three production stations two positions are provided as a buffer to guarantee a smooth production.

4.4 Girders
Both rail- and roadgirder are subdivided and produced in the same way. The subdivision is:
1 Hammerhead, including diaphragm, 18 m long
2 and 3 Innerwings of 18 m length each
4 and 5 Outerwings of 27.2 m length each.
The girders are moved perpendicular to their longitudinal axis and cantilever in the same way as they will after erection.
The production stations are thus:
1. Hammerhead
2. Innerwings
3. Outerwings
Again between the 3 production stations two buffer stations are introduced, where also additional work is done.
At each station the formwork consists of a fixed bottom mould and movable inner- and outer moulds. After pouring post tensioning is applied, so that the unit is self supporting and it can be skidded towards the next position.

5. ERECTION
All concrete units are placed with the catamaran shaped heavy lifting vessel Svanen, capable of lifting 6500 tons plus safety margin. To be able to lift the units, the production lines are extended into the harbour so that the Svanen can straddle them and connect the hoisting gear.
After removing soft overburden, a stonebed is prepared to receive a caisson, positioned within a tolerance of 100 mm by the HLV.
Both piershafts of one caisson are lifted and placed simultaneously. While resting on temporary flat jacks the construction joint between piershafts and caisson is poured. Both girders are placed on top of their piershaft, supported by 4 x 3 hydraulic jacks to provide a stable position. After pouring and prestressing the top joint between two consecutive girders, they rest on their permanent bearings.
6. LOGISTICS
The prefab yard has been developed for a concrete production of 1000 m$^3$ concrete per day, equivalent to a total output of 450,000 m$^3$ in 28 months. Basically, prefabrication is importing raw material to the site, aggregate them to half products, joining those to prefab units and exporting those from site. As 6000 ton units are not simply stacked, it is obvious that a major breakdown of the Svanen will almost immediately stop the production on the yard. On the other hand, failing to supply a single source item, say water, has the same effect. Each item is characterised by a "supplier" on one end and a "client" on the other. To cope with eventualities intermediate storage is required as a buffer for input and output at the various production centres. Primary production centres are the batchplan, the reinforcing steel yard and the prestressing unit (of course no output buffer for the batchplan, other than a few minutes truckmixer).
Secondary or main production units are the four production lines. Here the main concern is the number of storage positions for finished units. A large amount of stored units requires long and expensive production lines, but they do not necessarily have to be occupied. Offshore work is more susceptible to weather conditions than on shore work, particularly wind (and ice) in the winter season. Based on a six day production cycle, the Svanen has to erect 4 units in that time. Next table shows a possible sequence and storage required for caissons.
### Caisson Production Sequence

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#### Storage required

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The relative mild past two winters were the main factor, preventing the Svanen to become the governing factor for the storage chosen for the various units.

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[1] ESG - European Storebælt Group:
- Ballast Nedam
- Højgaard & Schultz A/S
- Taylor Woodrow
- C.G. Jensen A/S
- Losinger
- Per Aarsleff A/S
RECEIVED AFTERWARDS
Concrete CAD?!

N.B. Heuer
Concrete CAD?! 

Mr. Chairman, ladies and gentlemen,

Undoubtedly you will have noted that the title of my contribution to this symposium contains both a question mark and an exclamation mark. This was done to emphasize that the use of CAD systems in building construction in general and in the prefab industry in particular, has become essential for a variety of reasons, but that also targets are not reached when one limits oneself to CAD systems only.

To start at the end: not reaching targets is a direct result of the character of the building and the impact of its design on production, storage, transport and assembly. In principle the character of a building does not differ much in the various countries. It is different in other industries, meaning the large number of partners which produce that particular product: a building, or a bridge. All these construction partners have their own responsibilities, specific know-how and skills. When all these construction partners make use of CAD systems this will, in the most favourable case, lead to the best possible part product, but it will not automatically lead to the best possible end product: the building that our client had in mind.

Hence it will be obvious that integration of CAD systems of the building partners is a step in the right direction. In this country, but certainly also in neighbouring countries, countless initiatives are taken towards the integration of CAD systems. Although in the computer technical sense these problems can be resolved, in practice the advantages are disappointing.
This is a consequence of the overall process in the building construction sector. This overall process can be roughly subdivided into two phases. In the first phase the programme of requirements is drawn up by the principal. This programme of requirements is translated by the architect into a preliminary design, following which the architect, the main contractor and other consultants prepare the definitive design.

The last activity of the first phase is drawing up the building specification. The specification gives details of the design in the form of drawings and material specifications. In the second phase of the overall construction process the contracting parties start their work. Work preparation and production by the contractor and his subcontractors use the specification as starting point. On account of the earlier mentioned state of affairs of the first phase, greatly cost increasing bottlenecks in the second phase are becoming obvious.

The first cost increasing factor is that the design does not take into account the method of implementation that suits the contractor and the subcontractors who are carrying out the work. The contractor and subcontractors are compelled by the traditional specification to adapt their own well tried methods.

A second cost increasing factor resulting from the traditional method of contracting is the fact that work preparation by the contractor and the subcontractors can only commence after these have been selected to carry out the work. Consequently this work preparation must take place just before the start of the project, a period that is always characterized by lack of time. A very important aspect of the aforementioned preparations is, particularly, the coordination of information required by and from the contractor, prefab supplier, installation consultants etc. Besides, for each project these contracting parties are different as well.
On account of the brief preparation time and the inadequate coordination between the contracting parties, several problems may arise during the construction process. An example is that while the jigs and other components are standing ready at the prefab supplier, detail drawings are still being changed. Consequently expensive modifications to the jigs, reinforcing etc. have to be made, leading to a loss of production time etc.

In other words, the traditional methods create bottlenecks during construction. And bottlenecks have very annoying habits: the process time becomes longer (besides, we should not underestimate the cost involved). The amount of work in progress increases and the quality of the work suffers greatly. Yet another characteristic of bottlenecks that also affects other industrial sectors, is that using computers definitely does not solve these. The only way to avoid bottlenecks is to effect changes in the work methods in that part of the overall process where they are caused. The Dutch concrete industry has taken the initiative to table several proposals, developed in cooperation with the Ministry for Economic Affairs in the Netherlands.

The aforementioned first phase remains unchanged until its last part: preparing the specification. In effect the designers, the architect, the main contractor and the installation consultants are assisted in their decision taking by information from the various prefab systems. This information has been prepared by the Dutch prefab manufacturers especially for this purpose, it is not vendor related and it outlines the consequences of the selection of a prefab system.

These consequences do not only refer to the relationship between the foundations and the system, between the required stability facilities and the system and between the installations and the system, but these refer also to matters such as the production method, the assembly, costs etc. The information does not deal with the irrelevant details for the
decisions to be taken, for reason of not hampering any construction parties as yet unknown at the time of decision taking in terms of their specific work method. The great difference in the first phase of the construction process between the existing method and that proposed by the Dutch prefab industry, lies in the last stage of the design process: preparing the specification. Instead of contracting out after the specification phase, the contractor and the subcontractor should be selected prior to the specification phase. This has great advantages: preparing the specification by the architect and the consultants takes place at the same time as the preparations being made by the contractor and the consultants. Integration of the specification and the work preparation becomes possible and there is ample opportunity to completely synchronize the preparations of the contractor and the subcontractors. It will be obvious that, through this new work method, the process can be controlled much better, particularly as this controlled process will form the basis upon which implementation with the assistance of integrated planning systems, information systems and CAD systems can be optimal. In other words, by first changing the work method of the various construction partners, justice can be done to the CAD systems and objectives, such as faster process times, smaller quantities of work in progress, reduction of the cost of the entire building project and avoiding unnecessary cost of both the preparatory and the implementing partners, can be achieved.

At the beginning of my contribution to this symposium, I did mention, ladies and gentlemen, that the use of CAD systems as such does not give a guarantee that targets will be reached. One of the reasons mentioned was the impact of the design on production, storage, transport and assembly.

There is a difference between design and industrial engineering. The manufacturer of a prefab concrete structure
of an office building will prepare traditional drawings of the prefab elements, such as columns, walls, girders, floors etc. The drawback of this method is that the entire basic structure is often not consistent with the elements mentioned and that the draftsman of the prefab subcontractor cannot adequately and integrally take into account all requirements imposed by production, assembly etc. in terms of the design, let alone that he can incorporate all relationships between prefab concrete and systems, outer walls etc. in his design of the various elements.

Just using a CAD system replaces only the drawing board of the draftsman.

Industrial engineering is based on the total project and it has the fundamental characteristic that the design of the product is integrated with its production, including plans, production and quality control and the method of distribution of the product.

Nowadays the manufacturer of prefab concrete structures is not expected to produce standard items, but he should possess a high degree of flexibility. The mass production of the 1970s is not good enough any more. On the one hand our products should be standardized, but on the other hand they should be adapted to the specific wishes of the client. Consequently Industrial Engineering has become essential, also to the prefab manufacturer.

This different work method imposes demands upon the tools needed by the draftsman and hence also upon the CAD system. The CAD system must be 3-dimensional and the draftsman must design the links between the elements. The design of the elements themselves by the draftsman is then no longer necessary. Consistency between the basic structure and the elements consequently is guaranteed and this particularly is of very great importance in the event of changes being made in this structure. The integration of the structure with the office installations and the walls, will also be consistent when the design is based on the entire building project.
Design on this basis will not succeed with a CAD system only, if such a CAD system is not linked to a data base. However, such a data base must be of a special type. All information of the data base must be stored in such a flexible manner that element drawings, purchase lists and storage of components to be cast in, lists for despatch, for supporting material etc., are and will remain consistent in the case of changes. To take account of the specific method of production, transport and assembly by the manufacturer, the data base must contain basic information with which the requirements and arrangements for those products have been laid down. As a consequence the individual prefab elements meet production requirements. In such case the draftsman, by using such a CAD system has, as a matter of fact, no other option open to him.

Mr. Chairman, ladies and gentlemen, in conclusion let me say that making use of CAD systems in the building construction sector does not necessarily lead to the essential improvements in process time, cost control, quality etc.

The CAD systems of the various construction partners must be able to mutually communicate and that can only succeed, in my opinion, when changes have been made in the overall process of building construction.

The work method of the designer of the prefab concrete structures manufacturer, also will have to be changed, on account of the changing demands of our clients. Designs must be prepared not at the element level, but rather at the building level. 3D-CAD systems, linked to the correct data base, are then indispensable.
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