ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 4, NOS 2-4 (2003)
PAGES 149-161

A PROPOSAL FOR BEST PRACTICE IN DESIGN, DETAILING AND FABRICATION OF STEEL STRUCTURES IN DEVELOPING COUNTRIES BASED ON WORLDWIDE EXPERIENCE

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ABSTRACT

Based on worldwide practical experiences, a fully automated CAD/CAM system covering the process of design and fabrication for a complete spectrum of steel structures is presented in this paper. The system also supports cooperative planning for geographically distributed engineering offices and fabricators. A number of advantageous aspects of such system are also presented. It is believed that the limited capacity of the building industry in some developing countries is mainly due to its undeveloped planning process, including distributed design and detailing, as well as limitations in the fabrication procedures. Therefore, as the best solution, the paper proposes adaptation of a customised and localised version of this new technology. It is finally concluded that civil and structural engineers must particularly gear up to use such tools for a chance to make a successful transitional move to global markets and to make the local building industry strong enough for the challenges of the near future.

Keywords: computer integration, construction processes, CAD/CIM technology transfer

1. INTRODUCTION

Today, computer aided design and manufacturing (CAD/CIM) has proved to be a promising filed of practice in the course of a civil engineering project. This certainly serves as an efficient and powerful tool for the civil engineers to run and develop the building design process with the maximum speed and accuracy and thus, add significant value to the final building product. Theoretical models are the basis of computer-aided design and analysis for structural engineers′ tasks. In the building industry, object-oriented methods are used for product modelling, by which most diverse aspects of a building are described and reflect characteristics of a building, its construction units and their relations. Thus, with the use of building product models, it is now possible to visualize and verify the suitability of all building components just on the computer screen.

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Consequently, this recently applied science proposes the best solution to upgrade the civil engineering practice in countries where not-so-efficient conventional methods of practice are still being used. Moreover, the concept of integration plays a significant role in this solution since one of the major problems in these countries is the deficiency of planning process as well as in cooperative work. In other words, although each individual sector in the building industry may have a perfect standalone performance, they fail to function efficiently in an integrated set, which is the inherent need for a successful civil engineering within global competition. Therefore, this new research has obvious potentials to enhance the productivity in building design and construction, in developing countries. It can also open the doors of global success and competence for the civil engineers and will be of particular interest for structural engineers.

Based on a successful worldwide practice, a computer integrated design and manufacturing system, namely called BOCAD-3D, is introduced for steel structures, cladding glazing, and different advantageous aspects of this system are discussed here. The main idea of this system dates back to more than thirty years ago where the first author of paper for the first time, thought of adapting new mechanical engineering technology into industrial sector of civil engineering construction. The idea was to replace the handicraft labour in the workshop and on site by complete production lines comprising specific machines such as CNC-machines. Consequently the expensive workmanship would be eliminated as much as possible and automated process could lead to profitability and competency in the construction process.

In those days research on directly industry related topics, however, was against the mainstream of scientific research at civil engineering faculties that preferred to concentrate on Finite Element Methods. No doubt, FEM calculations are indispensable for the safety of buildings. But what if a perfect FEM analysis is followed by a poor construction? Will the goal of providing safety be fulfilled then? On the other hand, FEM-analysis is typically less than 5% of the total cost of a building. Why not investing scientific research on the topics with dominant financial importance, the planning, fabrication, and the erection processes, upon which profitability and competitiveness of the industry depends. Therefore, the innovative idea received financial support from the German government and thus a state of the art began to develop.

2. COMPUTER AIDED MANUFACTURING AND FABRICATION

Based on mechanical engineering practice, one of the very important components in manufacturing and fabrication is CNC machines. CNC-machines, as shown in Figure 1, are machine tools working automatically. Automat machines are well known for repetitive mass-produced products such as components of cars. CNC-machines however are designed to work as automat on a variety of individual work-pieces, not mass-products. Work-pieces right for a CNC-automat must only have characteristics in common. Driven by numeric stepper motors, the manifold units of a CNC-machine automatically move into individual working positions work-piece by work-piece.

What does this mean for civil engineering and specifically steel construction, cladding and glazing? Since all the steel building components have some characteristics in common such as the potential ability to get sawed, drilled or marked, they can be considered as ideal candidates to be machined by CNC-machines. The same is the case for metal sheets like gussets or stiffeners, needing flame-cutting, drilling and marking. So new CNC-machines for steel structures were born, see Figure 1.The first big CNC-machines for steel beams were introduced into industry at pilot users.

Strong refusal of practitioners towards these very expensive CNC-machines and their feeder units had to be overcome by the practical proof of profitability. The first pilot users suffered some run-in problems at the beginning, but then proved excellent profitability. Without CNC-machine and modules, the industry would have needed one person to trace the drawing information on the beam and a crane driver in addition to some other labours to operate the saw and the drilling machine. With a CNC-automat and its feeder units, one person only is needed to supervise a production line. So, CNC-machines became state of the art. Today, the enormous demand for these innovative machines in Germany has decreased their prices from about 1 to 0.2 million Dollars or less for second hand machines.

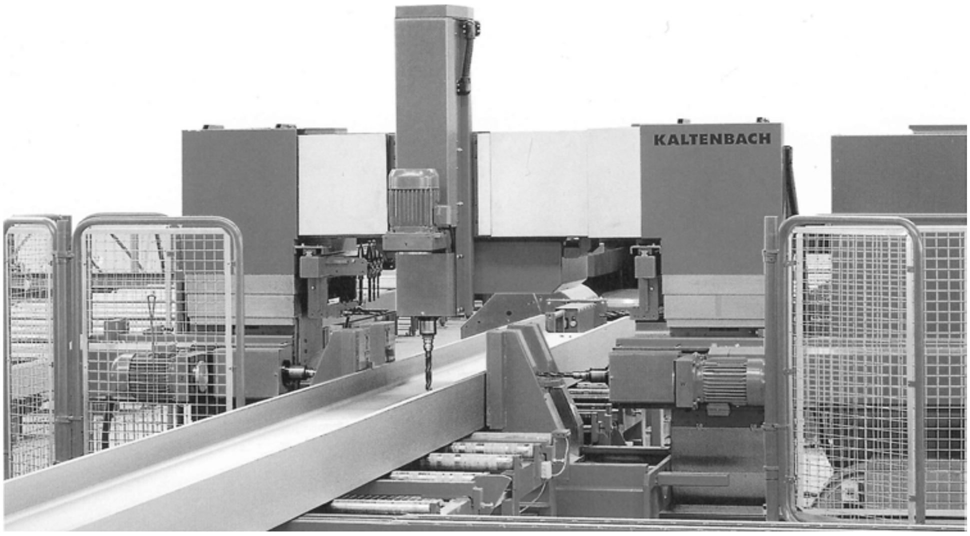

Figure 1. CNC-centre to drill, saw and mark, courtesy Kaltenbach, Germany

How this situation is compared to steel construction fabricators in some developing countries? As long as wages for skilled labourers in workshops are low in such counries, it might not be a good argument to make them more efficient by expensive CNC-machines. But do we have to wait until we get the same wages for the same work worldwide? There is another key-criterion in favour of CNC-machines in developing countries. CNC-machines are the decisive step to gain reproducible precision of products. With CNC-processing, steel components will exactly fit to dimensions planned. Adjustments on site at erection, caused by classical handicraft tolerances, are eliminated. In some developing countriues, certain construction methods are often used which require unnecessary constructiuon time for operations like acetylene cutting and drilling.

The virtue of reliability-correct and fair delivery time, perfect functionality, and cost as budgeted - is decisively enhanced by CNC-production.

3. COMPUTER AIDED DESIGN AND DETAILING

Based on this outstanding market position, a unique input language for CNC-machines, called NC-DSTV, was developed by the team of the first author in order to achieve a global standardization for CNC-machines. The sweeping innovation success of CNC-machines at steel construction fabricators gave some reputation to his research team.

Substantial development funds for higher targets were granted. This target was a complete building oriented software system BOCAD-3D for "Computer Aided Design, Detailing and Fabrication of Steel Structures" with some revolutionary ideas. The ideas derive from basic differences between mechanical and civil engineering products, as we will see.

The fact that the steel construction products are quite homogeneous compared to the full range of mechanical engineering products will lead to a higher level of efficiency and automation for a specific, less complex CAD-system.

3.1 3D-modelling instead of 2D-drafting

Definitely buildings are 3D-objects as indicated in Figure 2. A 3D-CAD system enables the engineer to have any chosen view of the building in order to ease his interactive modelling work. . It is of course much more difficult to develop a Computer Aided Design software system based on 3D modelling instead of 2D drafting. The principle of 3D modelling strictly eliminates contradictions between any 3D-components of the building and between different drawings of the building, when a unique 3D-model is used. Like a photo shot, each technical drawing is nothing else but a special view of the unique 3D-model. Also, lists or CNC-data are just specific data filtered out of the 3D-model by appropriate rules.

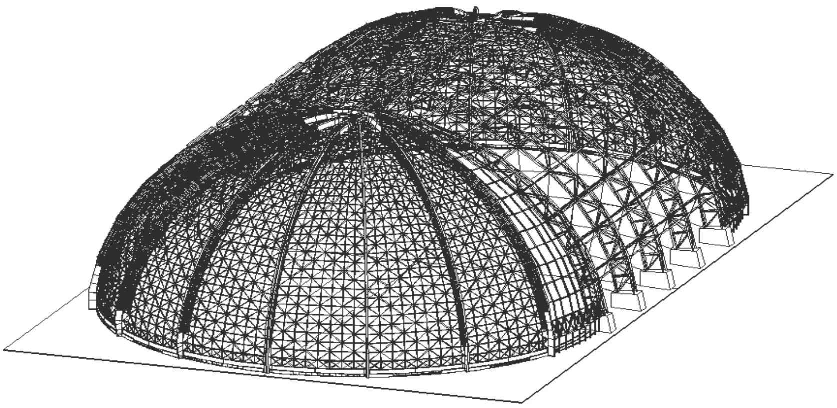

Figure 2. Cargo lifter Hangar in Brand, Germany, courtesy BOCAD Software, Germany

Another advantage of a 3D-CAD system is the simplified checking process. In other words, if the 3D-model is correct, all the subsequent processes done by the program will be correct. The 3-D model is the central source of all information. Therefore the checking process can be cut down to the final results avoiding the checking of every intermediate step. In traditional 2D modelling, not only the general assembly drawing, but also each component′s drawing is checked and approved. During this process several technical revisions due to insufficient understanding of the as-built model has become a commonplace. With all this effort and correction, there are still some errors left that will be only seen during the construction. This has led to the present situation where the as-built drawings are typically different from initial shop drawings. In this situation, opportunities for a reliable and an effective process are missed and seeds of process inefficiencies like late change orders, rework and poor allocation of resources are sown. This situation cannot be helped as far as the drafting is done in 2D. As a solution, a 3D-modelling process capable of rendering reliable output will be obviously instrumental. A lot of frictions, costs and waste of time are eliminated by such a CAD-system.

3.2 Automatic detailing, where applicable

The interactive workload of the engineer at the screen of a PC can be reduced sharply by CAD-methods containing the logic for automatic detailing. For example, a complete node detailed as rigid connection between a column and a girder, as shown in Figure 3, then calls for only three clicks: the choice of the appropriate type of rigid connection and the two members affected. This whole time consuming task in 2D drafting workspace is reduced to only three clicks in a 3D-modelling platform.

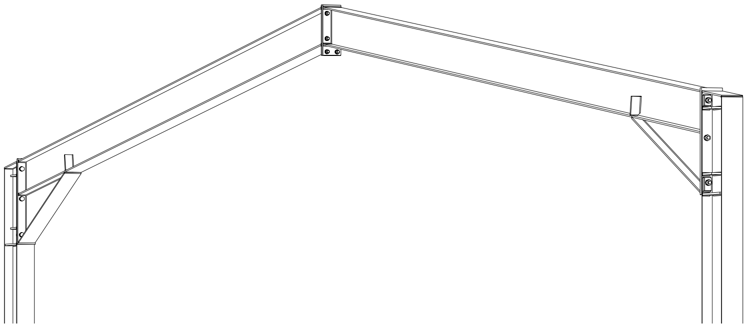

Figure 3. Automatic detailing by CAD-methods, type of a rigid connection, courtesy BOCAD Software, Germany

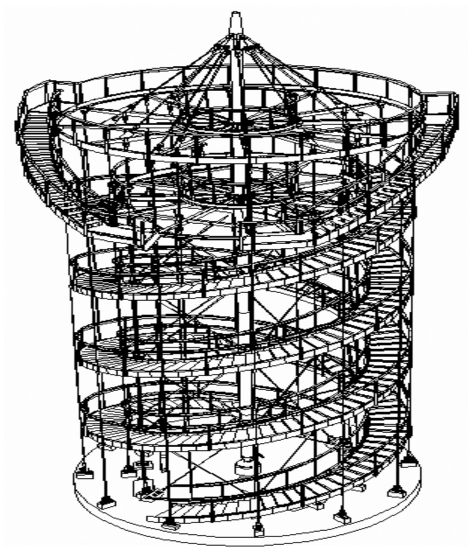

Figure 4. Observation tower, Stuttgart, Germany, Courtesy Schlaich, Bergermann and Partner

3.3 Powerful tools for individual detailing

A powerful library of CAD-methods for all kinds of industry-used connections and components was developed in order to make the interactive work of engineers highly efficient and systematic at a time. Only the remainder of individual nodes and components not covered by CAD-methods have to be done by basic interactive steps. Figure 4 shows such an exceptional case where the structure and its individual staircases have been developed by these efficient steps.

3.4 Strategic rules of representation used for drawings

Drawings done for different purposes must show different representations. For example in workshop drawings hidden lines must be represented as dotted lines whereas perspective drawings must hide hidden lines to be legible. So, when all kinds of drawings are like photo shots of the same computer based 3D-model, each photo shot must use appropriate rules for how to represent and comment each individual element of the 3D-model shown in the drawing. It should be noted that here again all individual necessary views, sections, holes, welds and comments (as needed in the workshop) are analysed and arranged by the CAD-system itself.

To keep this process completely flexible, it is possible to define different sets of rules for representation of the drawing for any particular purpose. As a result, adjustable rules for automatic processes are a decisive idea to be successful in industry. This is the only way to gain leadership for best practice worldwide.

3.5 Product rendering and virtual reality

In the course of a building project, it is often necessary to visualise the final building product most preferably in a 3D view. Therefore, a set of graphical and rendering tools has been designed in the program to facilitate product visualisation in a move-through 3D virtual environment. Subsequently, the program is able to automatically render the 3D objects depending on their materials and thus gives the objects more real and tangible solid entities than just 3D objects made by lines. This obviously offers a better and more extensive tool for decision-making/briefing of designers, architects, owners, and facility/building managers. Figure 5 shows an example of such an output where both the 3D perspective and the rendered picture of the famous Musical Dome in Köln are presented.

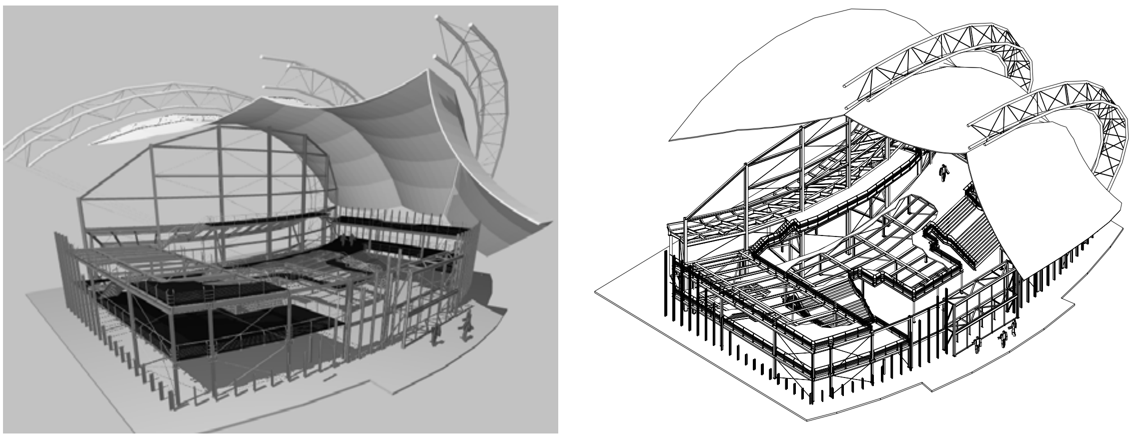

Figure 5. Musical Dome, 3D and rendering perspective, Köln, Germany, courtesy BOCAD Software, Germany

3.6 Automatic detection of repetitive components and their marking

In the course of design and detailing of any building, repetitive components can arise. Detection and indication of the repetitive components when designing and detailing is a profitable strategy, because firstly fabrication and erection of identical components is faster and reduces errors and bureaucracy and secondly in the construction of big buildings, it is a difficult task, if not impossible, to keep track of all components of the same geometry and same attributes like quality. Therefore, the program can automatically detect the repetitions of the components in the 3D-model of the building and assigns them an identical mark number. The representation of the mark numbers may be done based on any contractor's preferences. This will offer the contractor an opportunity to determine the best way of representation suited to his construction process. With these individual rules how to compose automatically mark numbers and with the possibility to filter out components to be marked under given criterion, all customers worldwide are very satisfied enjoying "the best practice".

3.7 Automatic calculation of all kinds of drawings, lists and CNC-data

When an engineer works interactively with the CAD-system, he uses several "windows" on the screen showing pictures of what already has been modelled as 3D-model. Each window on the screen can show different views of the 3D-model to ease interactive operations of the engineer. An important feature of the program is that the results of any action, for instance a new wind bracing, is immediately shown in all windows on the screen respecting the actual representation-rules of each window. This way, when modelling the building step by step, one or more windows with views emerge from the engineer's activities, which look like general arrangement drawings. Engineers often use simplified representation rules for better clarity on small screens. But any time a recalculation of a view with the representation rules typical for general arrangement drawings will show a view as the customer demands. This drawing then can be sent directly to the customer by e-mail or output on a laser printer. General arrangement drawings therefore are resulting from the interactive definition of the building's 3D-model anyhow.

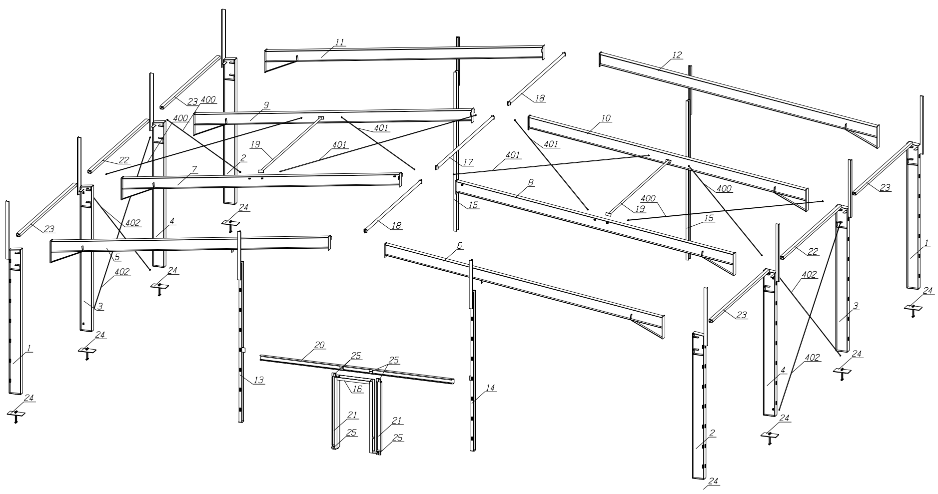

Figure 6. Exploded view for shipping and erection, automatic result, courtesy BOCAD Software, Germany

The program can automatically create any other outputs such as workshop drawings for assemblies, exploded views, quantity lists sorted by mark numbers, material lists, bolt lists, assembly lists or shipping lists. In addition, CNC-data only need a click to be done and transferred to the CNC-machines.

The most advanced steel construction fabricators use exploded views Figure 6 to control all workshop information. In addition to all workshop drawings needed for assemblies also exploded views with the complete phase to be assembled are put up at every assembly station at the workshop. This will make the process of assembling and erection more convenient and tangible and thus avoids typical errors. Moreover, the manager of the workshop is able to keep track of the construction progress by the exploded views of the drawing.

Imagine the growth of profitability considering the fact that about 70% of the capacity of conventional drafting offices is swallowed up to do the workshop drawings. A typical general arrangement drawing of an Iranian oil processing plant, reduced from format DIN A0 to be published in this paper, is shown by Figure 7. This technology has also been adapted to other countries than Germany such as Belgium Figure 8 and Kuala Lumpur Figure 9 by BOCAD Service International (Belgium).

4. CLADDING AND GLAZING APPLICATIONS

Cladding, the skin of a building, mostly is more expensive than the steel structure of the fuilding. Characteristics of computer aided design and detailing for steel structures are quite similar to cladding characteristics, but also show decisive differences. For design and detailing of the cladding the same unique 3D-model used for steel detailing is used for architectural buildings famous all over the world, shown in Figures (2, 8-9).

The differences in the nature of structural elements and cladding elements lead to reasonable differences of drawings, lists, tolerances, shipping precautions, marking, fabrication and erection. As a way of illustration let us look at the general arrangement drawings for cladding. Figure 10 shows the general arrangement drawing of a roof made by trapezoid panels. Areas with equal panels are automatically indicated by a diagonal including their mark number and their quantity. As a noticeable difference to structures fabricated turnkey in the workshop, cladding panels get cut-outs at erection on site, because otherwise they would be too unstable for transportation. That is why panels with different geometry caused by cut-outs must get the same mark number, if the section and the overall dimensions are equal, see Figure 11. So, the rules for the automatic detection of equal cladding elements differ decisively from rules for structural elements.

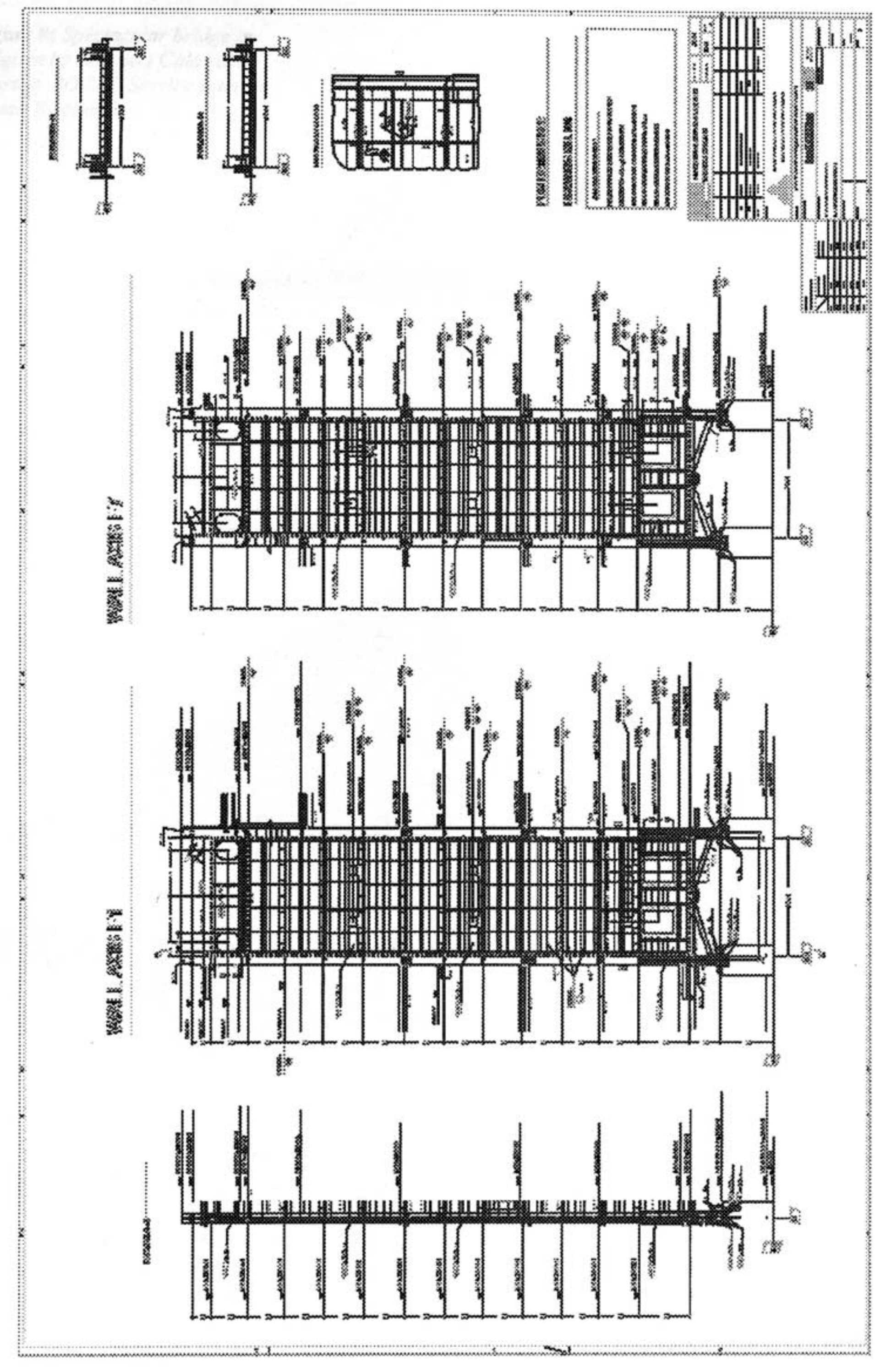

Figure 8. Spectacular bridge in Belgium by architect Calatrava, courtesy BOCAD Service International, Belgium

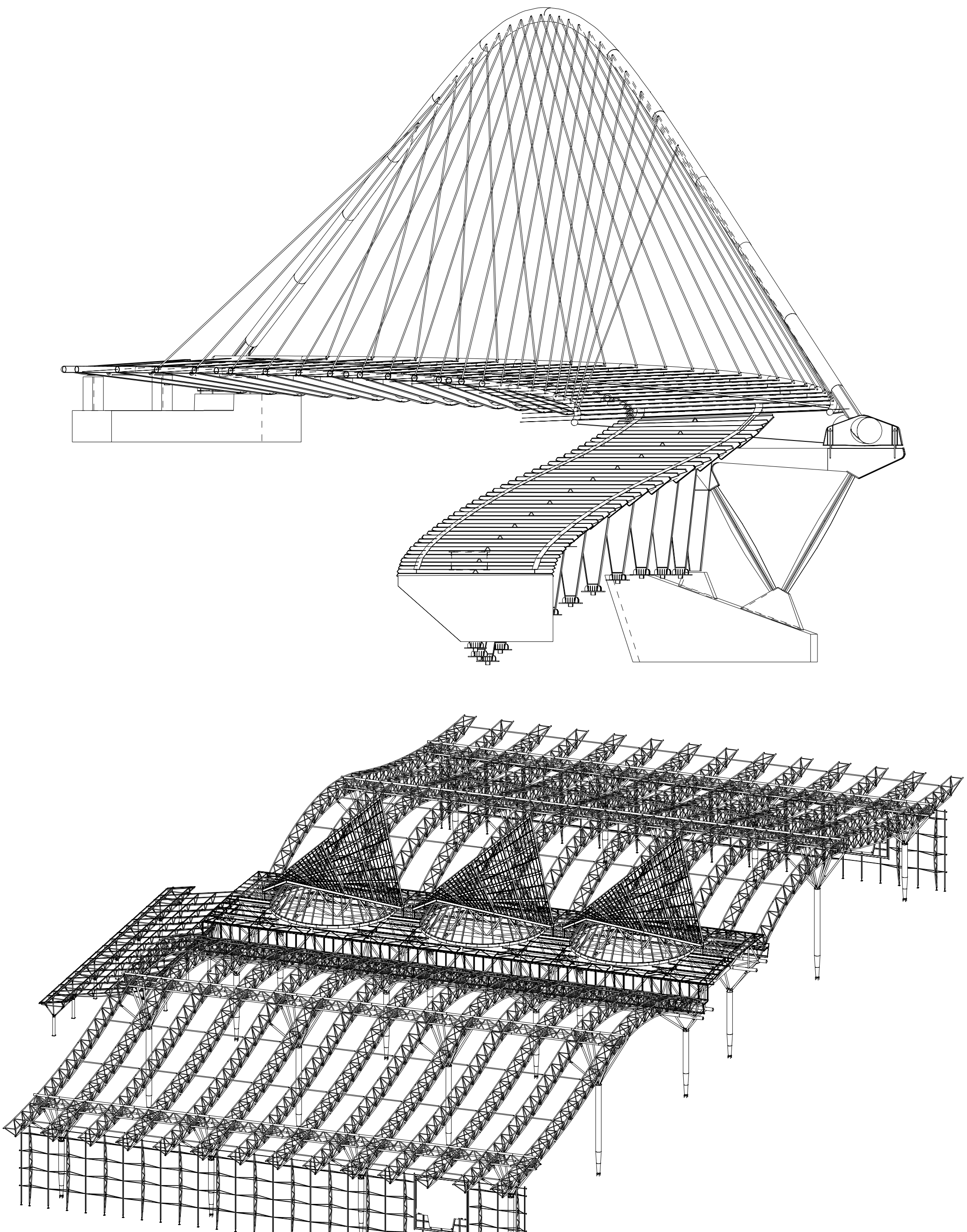

Figure 9. Central station Kuala Lumpur, Malaysia, courtesy BOCAD Service International

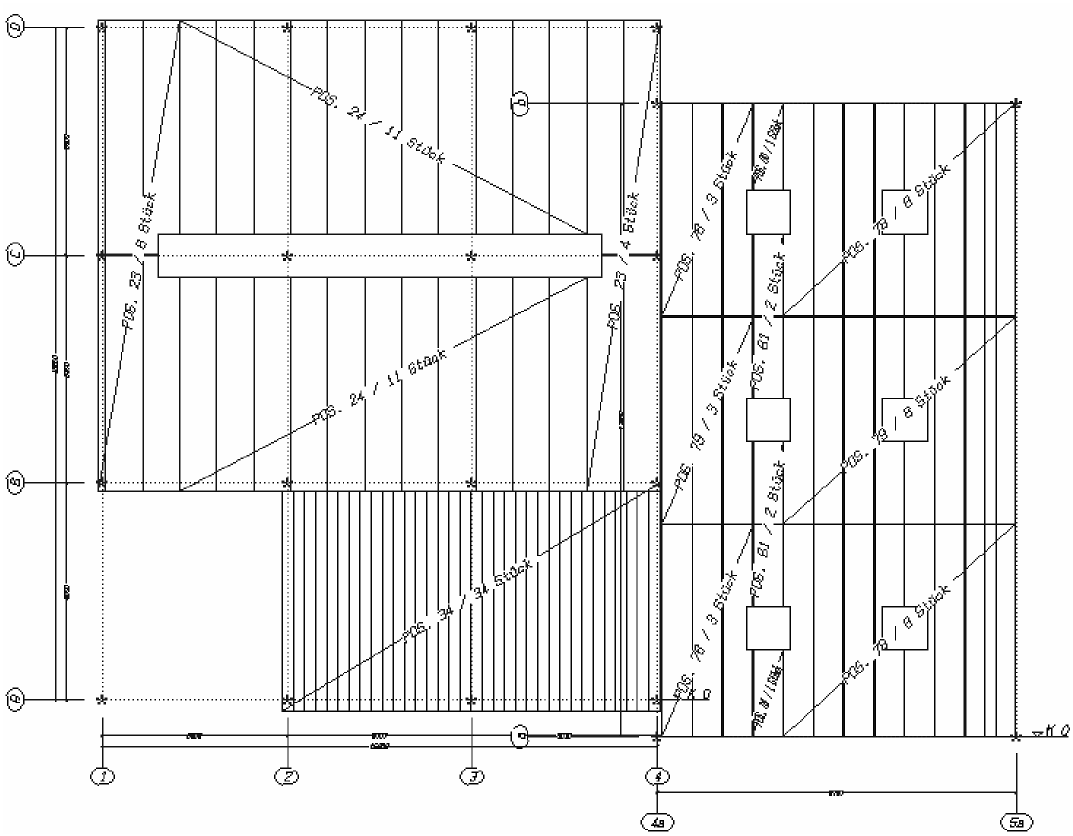

Figure 10. General arrangement drawing for cladding of a roof, automatic result, courtesy BOCAD Software, Germany

The arguments discussed for cladding are even more important for glazing, the most expensive components of a building. Glazing has a very specific nature and therefore intensive research and development had to be done to achieve the same level of computer aided design, detailing and fabrication using one unique again 3D-model. Figure 11 proves some specific output for glazing, as used in industry showing best practice worldwide.

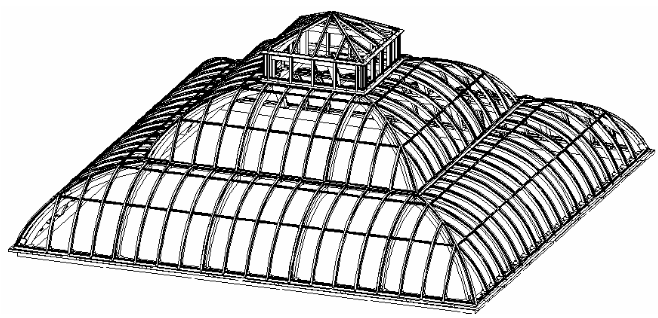

Figure 11. Glazing example with curved glazing (clipped), courtesy BOCAD Software, Germany

5. CO-OPERATION IN A WORLDWIDE NETWORK

Design and detailing of the big buildings such as high-rise or industrial structures, often calls for simultaneous collaboration among a critical mass of engineers particularly when the deadline pressure is tight. Moreover, the specific experts are often geographically dispersed and usually much time and money is spent to harmonize their effort. Now the question is how these experts can cooperate efficiently with perfect bug-free results. Here again BOCAD-3D provides the platform for distributed cooperative planning over the world wide net.

All big buildings shown here have been designed and detailed by BOCAD-3D and many engineers working parallel at the same time. Everybody, who had done his task, exported his subsystem into the central database on a server of the computer network. Everybody else imported the subsystems of colleagues he needed from the server to his PC to continue his own work. Therefore, better management on information exchange and sharing is made possible and the need for investments on many short/long distance trips as well as local offices would be eliminated.

For further information, please see a list of selected papers in references [1-11], which cover the basic concepts as well as some advanced aspects of the theory and practice of computer aided design, detailing and fabrication.

6. CONCLUDING REMARKS

A highly sophisticated 3D-CAD-system can be very instrumental in the hands of structural engineers, for it eliminates all sources of costly errors and conflicts. The software introduced in this paper is capable of producing all steel detailing and drawings, material lists, planning, fabrication and the CNC-data. This CAD-system also allows cooperative planning when a critical mass of experts is involved to collaborate simultaneously especially in big building projects. Some practical examples of worldwide applications were also presented, indicating a growing global interest on application of CAD-systems in building industry including some industrial buildings in Iran.

While applied Information Technology (IT) in the planning process seems to be a promising field with significant potentials; the building industry in some developing countries has been slow to adopt the technology. Adaptation of any new technology involves understanding and localizing that technology, in order to make it the best choice suited to the demands of the local market and industry. However, as long as conventional methods of design and construction are used, transferring this new technology/system, with a localized perspective, is the ultimate challenge.

The advantageous aspects of such a system presented here must be encouraging for the Iranian civil engineers to innovate their respective industry by thorough utilization of this technology. This is their best chance if they intend to join the international markets and make themselves fit for the global market and competence. Likewise, on national basis, the Iranian civil and structural engineers need to enhance the productivity of the building industry to make issues such as housing affordable for younger generation. No doubt, the growth in population in Iran (65% of the population under 30 years) asks for very powerful and efficient building and construction processes to fulfil the basic needs of building and housing. Therefore, new trends have to be set to make civil engineering and the local building industry in Iran fit for this demanding task and simultaneously creating new jobs in civil engineering for the young generation.

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